EFFECTS OF THINNING ON ABOVEGROUND CARBON SEQUESTRATION BY A 45-YEAR-OLD EASTERN WHITE PINE PLANTATION: A CASE STUDY

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ABSTRACT

Aboveground carbon sequestration by a 45-year-old plantation of eastern white pines was determined in response to thinning to three levels of residual basal area: (1) Control (no thinning), (2) light thinning to 120 feet^2/acre and (3) heavy thinning to 80 feet^2/acre. After 11 years carbon stocks were lowest on the heavily thinned plot, but there was little practical difference between carbon dynamics on the unthinned and lightly thinned plots. Carbon stocks of an adjacent 113-year-old unthinned reference hardwood stand of mixed oaks were about half that of the unthinned pine plantation. Results from this unreplicated pilot study are useful primarily for planning future investigations.

INTRODUCTION

Forests are an important long term, but temporary, sink for carbon (Johnsen and others 2001). Until other technology becomes available, however, forests provide an immediate means for storing atmospheric carbon dioxide, which is believed to be an important factor contributing to climate change (Birdsey 1992). Carbon storage pools and rates of sequestration by soil and vegetation may be altered by management decisions such as species selection, rotation lengths and basal area stocking (Foley and others 2009). Dense, plantings of conifers are particularly efficient for carbon sequestration as has been demonstrated for loblolly pine (Pinus taeda) in the favorable climate, terrain, and soils of the southern US (Richter and others 1999).

Eastern white pine (P. strobus) (hereafter white pine) has long been recognized as an important native conifer of the southern Appalachian Mountains (Pinchot and Ashe 1897, Holmes 1911) that has been widely managed for timber production in the Lake States and New England (Burns and Honkala 1990). It has many characteristics desirable for carbon sequestration such as extended longevity, accumulation of high levels of aboveground biomass, commercially valuable, favorable response to management, relatively few insect and disease problems, and ease of regeneration by planting (Sohngen and Brown 2008). White pine is recommended as a highly desirable timber species for small tracts of marginal site quality (Dierauf and Scrivani 1995, Clatterbuck and Ganus 2000). Small forest tracts are also receiving increased attention for their potential to sequester carbon (Hoover and others 2000). Carbon sequestration by white pine has been reported for extensive areas where it is a component in stands of mixed species (Birdsey 1996).

Carbon sequestration by mature white pine plantations has not been reported in the southern Appalachians. Carbon storage by white pine could compare favorably with other conifers because of the high levels of biomass attainable in densely stocked stands, even on sites of marginal quality (Huntington 1995). The primary purpose of this study was to quantify carbon stocks and the rate of carbon sequestration by a planting of white pine in response to levels of residual basal area stocking. A secondary objective was to compare carbon dynamics of the white pine planting with an adjacent unmanaged, natural stand of upland hardwoods. The scope of my study was limited to the aboveground carbon stocks of a single stand. Inadequate experimental material allowed installation only of a nonreplicated case study, the results of which are useful primarily as a source of information for planning further investigations.

MATERIAL AND METHODS

STUDY SITE

The study was conducted in the Bent Creek Experimental Forest, located about 10 miles southwest of Asheville, N.C., in the Pisgah National Forest. The experimental forest occupies most of a 6,300-acre watershed typical of the southern Appalachian Mountains that ranges in elevation from about 2,100 to 4,000 feet and includes two landscape-scale ecoregions: broad basins and low mountains. Soils are

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derived from metamorphic rocks, primarily gneisses and schists. Winters are short and mild, with a January mean temperature of 36°F. Summers are long and warm, with an August mean temperature of 75°F. Annual precipitation averages 45 inches in the basin ecoregion and is uniformly distributed among the seasons.

The study was installed in the basin ecoregion of the experimental forest on a 9-acre tract with uniform soil and history of recent land use, beginning with settlement by European immigrants in the early 1800s. Soils are classified as Typic Hapludults and are mapped as a complex of Evard-Cowee series that are deep (>40 inches), highly acidic (pH<5.5), well drained and characterized by an accumulation of clay in the B horizon. For almost 100 years the tract was part of a farm where land was utilized for subsistence agriculture, which likely included a repeated succession of uses including woodlot, cultivated field, and unimproved pasture (Nesbitt 1941).

Disturbance associated with agriculture ended with purchase of the tract (and extensive surrounding lands) by the USDA Forest Service from the Biltmore Estate in 1914. Balch (1928), in the first designed ecological study installed in the newly established experimental forest, reported vegetation on old field sites in the basin ecoregion consisted of a shade intolerant overstory mixture of pines (shortleaf (Pinus echinata), Virginia (P. virginiana), and pitch (P. rigida)) and oaks (black (Quercus velutina), scarlet (Q. coccinea), and white (Q.alba)), a midstory of tolerant hardwoods (sourwood (Oxydendrum arboreum), blackgum (Nyssa sylvatica), dogwood (Cornus florida), and red maple (Acer rubrum), and an understory of tree seedlings and saplings, and ericaceous shrubs. There is no record or evidence of fire occurrence during the past 50 years. Site index for upland oaks averages 70 feet at 50 years of age.

Use of about half of the tract changed in early 1952, from old field succession to planted pine plantation, which resulted in two forest types suitable for installation of the study described herein. On a 5-acre parcel of the tract, vegetation was clearcut and planted with white pine seedlings as a demonstration of rehabilitating low value hardwood stands. Vegetation on the adjacent hardwood parcel remained largely undisturbed until 1974, when the pine overstory was harvested to salvage mortality resulting from an extensive outbreak of southern pine beetle (Dendroctonus frontalis) throughout the experimental forest (Ward and others 1974). Additional salvage logging occurred on the hardwood parcel in 1987, to utilize an average of five large (>18 inches dbh), old (mean 103 years) scarlet and black oaks per acre that had died likely from stress associated with several years of severe drought. More recently, in late 1995, the remnants of Hurricane Opal caused windthrow of scattered large scarlet oaks in the hardwood stand. The adjacent pine plantation had been thinned by an unknown amount in 1968, but unlike the hardwood stand showed no apparent effects of disturbance from insects, droughts, or hurricanes. The white pine plantation was used to evaluate carbon dynamics resulting from thinning treatments and the hardwood stand was used as a reference or base line for comparison with a mature natural stand of unmanaged, endemic arborescent vegetation. When this study was installed in early 1997, the pine plantation was 45 years old and the hardwood stand was about 113 years.

THINNING TREATMENTS

The central part of the plantation was subdivided into three plots, each about 0.9 acre. Each plot was assigned one of three thinning treatments. Treatments consisted of thinning from below to three levels of residual basal area: (1) control (no thinning), (2) BA120 – residual basal area of approximately 120 feet^2/acre of basal area, and (3) BA80 -- residual basal area of approximately 80 feet^2/acre. After thinning, the population of all live stems ≥2 inches diameter breast height (dbh) on each plot was inventoried from individually identified trees and recorded by species and diameter. The treatments were made as part of a commercial timber sale and probably had been selected originally as appropriate for a conventional silvicultural study of stand response to thinning. Careful records were not maintained for trees harvested from each plot for use in calculation of carbon sequestered as timber products; the preharvest stand was reconstructed for both of the thinned plots.

In the hardwood reference stand, five small (0.05 acre) permanent plots had been systematically established in 1996 to quantify disturbance from Hurricane Opal. Those plots were relocated in 2008, each was expanded in area to 0.1 acre and vegetation was inventoried as for the pine plantation. The hardwood stand was considered as fully stocked even though basal area reductions similar to thinning had occurred in 1974, 1987, and 1995, which likely caused differential growth response of residual trees. No large scale disturbance has occurred in the hardwood stand since 1995, although senescence and death of individual large trees has continued, particularly among the scarlet oaks.

CARBON STOCKS ESTIMATION

Carbon stocks for both the pine plantation and hardwood stand were estimated for dry wood and bark of the main stem following standard methods that utilize either biomass or volume and specific gravity (Hoover and others 2000). White pine biomass was estimated for each tree using an allometric prediction equation based on dbh that was applicable over a wide range of tree sizes in Maine (Young and others 1980); a suitable model was not found for the southern Appalachians. For hardwoods, volume was estimated by species using models based on dbh developed in the southern Appalachian Mountains by Clark and Schroeder (1986). A generalized prediction equation for mixed hardwoods was used for species not represented in their study (e.g. sourwood). Biomass was estimated from volume using specific gravity for each species or group of species (Clark and Schroeder 1986). Carbon content of the biomass was estimated using a standard conversion factor (i.e. 50 percent of dry biomass) reported by Pearson and others (2007).

The effects of the residual basal area thinning treatments on carbon dynamics were determined after 11 years, in early 2008. Two response variables were evaluated for the three white pine plots and the hardwood reference stand: (1) carbon stored in both the harvested timber products and total aboveground carbon stored in the residual trees and (2) mean annual rate of carbon sequestration. Lack of replication precluded statistical assessment of differences among the three thinning treatments. For similar reasons, comparison of carbon storage and rate of sequestration by the white pine plantation with the reference hardwood stand could not be statistically tested.

RESULTS

After 11 years of response to thinning, white pine basal areas of the control, BA120, and BA80 treatment plots had increased 16.1, 31.1, and 39.3 percent respectively (Table 1). For the hardwood reference stand, basal area at the beginning of the study was about 31 percent that of the unthinned white pine plot and at the end of the study had increased slightly to 36 percent. The large increase in tree density in the hardwood stand, from 244 to 386 stems per acre, resulted mostly from ingrowth of white pine saplings that had originated from seeds windblown from the adjacent plantation.

Pretreatment white pine carbon stocks were estimated to be slightly lower on the BA80 residual basal area treatment compared to the Control and BA120 treatments (Table 2). In early 1997, immediately after thinning, 44 percent of the standing carbon stocks had been harvested from the BA120 residual basal area plot and 65 percent from the BA80 plot. At the end of the study period, the net increment of carbon storage in standing trees ranged from 11.7 tons on the BA120 treatment to 8.5 tons on the BA80 treatment. The rate of carbon sequestration by white pines on the Control and BA120 treatment plots was similar at about 1 ton/acre/year.

Hardwood carbon stocks averaged 21 tons/acre initially and increased to 25 tons/acre after 11 years (Table 2). The rate of sequestration averaged almost 0.4 ton/acre/year. In comparison with the unthinned white pine treatment, the hardwood reference stand stored only about half the carbon at the beginning and end of the study, but the rate of sequestration was only a third, due largely to unutilized mortality.

DISCUSSION

Results of this pilot study suggest that aboveground carbon storage by white pine was not increased by thinning from below to reduce residual basal area. Carbon sequestration on the BA120 treatment was about the same as that of the unthinned Control when initial basal area was reduced by 44 percent. The BA80 basal area treatment, however, reduced the rate of carbon sequestration by 0.24 ton/acre annually compared to the Control. McNab and Ritter (2000) reported similar findings based on volume rather than biomass, suggesting that although thinning captures probable mortality it does not appear to increase productivity of mature white pine plantations in the southern Appalachians. A potentially useful finding of this study was that the 45-year old white pine planting receiving the BA80 treatment stored about twice the amount of carbon compared to the older hardwood stand with about the same level of basal area stocking.

The rates of aboveground carbon accumulation by the Control treatment of white pine in this study were about midway in the range reported for other highly disturbed sites elsewhere in the East (Table 3). Carbon sequestration by the reference hardwood stand in this study (0.4 ton/acre/year) was similar to that reported for an oak stand in Minnesota (0.5 ton/acre/year). Carbon storage by the unthinned white pine plot in this study, however, was only about half that for a younger stand of loblolly pine in the piedmont of South Carolina. Although plantations of white pine can equal the biomass of loblolly pine (Kinerson and others 1977), carbon storage will generally always be less because of differences in wood specific gravity (0.34 vs 0.47). Longer rotations, however, may be a feasible method for increasing carbon stocks of managed white pine forests (Huang and Konrad 2006, Foley et al 2009).

Results of this pilot study are not suitable for making forest management decisions related to carbon sequestration by white pine plantations. My results do, however, suggest the importance of considering possible unintended effects that certain tree species selected for carbon management might have on other land resources. For example, annual water yields are less from large watersheds planted with white pine compared to a cover of natural hardwoods (Swank and Miner 1968). However, most of the reduction of water results from interception of precipitation by the evergreen foliage of white pines during the winter months, when soils are usually at field capacity during years of normal rainfall

(Beck 1985). Other issues to consider when evaluating white pine for carbon management are presented by Bennett and Desmarais (2003).

In summary, results from this unreplicated case study suggest that short-term aboveground carbon storage by white pine plantations is not increased by thinning and also that nearly mature white pine plantings may store more carbon than older natural hardwood stands. More specifically, basal area may be reduced by almost 50 percent in older, fully stocked white pine plantations on low quality sites in the southern Appalachians with little reduction in the rate of carbon sequestration. However, results from this preliminary investigation are not intended for management decisions and are presented primarily for demonstration and as a source of information to guide future studies.

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Table 1—Average (standard deviation) dimensions of the tree stand in the white pine plantation and hardwood reference stand at the beginning (1997) and end (2008) of the study in the Bent Creek Experimental Forest

Year	Thinning treatment[a]	Basal area[b]	Tree density	Quadratic mean dbh
		feet^2/acre	number/acre	inches
Eastern white pine plantation				
1997	Control	244.3[d]	230.5[d]	13.9
1997[c]	BA120	132.5	98.9	15.7
1997[c]	BA80	76.3	48.1	17.1
2008	Control	283.6	207.1	15.8
2008	BA120	173.7	96.6	18.1
2008	BA80	106.3	45.4	20.7
Hardwood reference stand				
1997	None	75.3 (15.7)	244.0 (38.5)	7.5
2008	None	103.5 (17.3)	386.0 (80.2)	7.0

[a]Treatments: White pine plantation – Control, no thinning; BA120, thin to residual basal area of 120 ft^2/acre; BA80, thin to residual basal area of 80 ft^2/ac. Rationale for the selected levels of thinning is unknown, but the BA120 level was likely in consideration of the B-line of residual basal area as the minimum stocking for maximum growth of white pine stands in New England (Leak 1982). Hardwood reference stand – Treatments were not made in this stand, which provided a comparison with the adjacent pine plantation.
[b]Basal area (<2 ft^2/ac) of scattered suppressed hardwoods in the white pine plantation was excluded. White pine site index (mean total height of dominants and codominants at 50 years of age) for each treatment was: Control=99, BA120=98, BA80=95.
[c]Stand characteristics after thinning. Prethinning basal area of the BA120 treatment was 234.8 feet^2/acre and 227.6 feet^2/acre on the BA80 treatment.
[d]Standard deviations are not presented for values of the white pine plantation because the population of trees was inventoried on each treatment plot, unlike in the hardwood stand that was sampled.

Table 2—Aboveground carbon stocks before (1997) and after (2008) installation of three thinning treatments in an eastern white pine plantation and an unthinned hardwood reference stand in Bent Creek Experimental Forest

Thinning treatment	1997 carbon stocks			2008 carbon stocks		Net change of carbon stocks[b]	Rate of carbon sequestration[c]
	Initial	Harvested	Residual	Standing	Total[a]		
	tons per acre						tons/ac/yr
White pine plantation							
Control	46.7	0.0	46.7	58.1	58.1	11.4	1.04
BA120	50.1	21.9	28.2	39.9	61.8	11.7	1.06
BA80	45.4	29.5	15.9	24.7	54.2	8.8	0.80
Hardwood reference stand							
None	21.1	0.0	21.1	25.3	25.3	4.2	0.38

[a]Sum of carbon harvested in 1997 and standing in 2008.
[b]Difference between standing carbon stocks in 2008 and residual stocks in 1997.
[c]Average annual carbon storage in harvested wood and standing biomass during the 11-year study.

Table 3—Comparison of rates of aboveground carbon sequestration by forests on disturbed sites in the eastern US

Forest type (state)	Stand age	Rate of carbon sequestration	Source
	years	tons/ac/yr	
Oak hardwoods (NC)	113	0.4	This study
Oak hardoods (MN)	39	0.5	Johnston et al (1996)
Pine-hardwoods (GA)	70	0.7	Huntington (1995)
White pine (RI)	115	0.7	Hooker (2003)
White pine (NC)	45	1.0	This study
Loblolly pine (VA)	47	1.4	Schiffman and Johnson (1989)
Loblolly pine (SC)	35	1.9	Richter et al. (1999)