DOI: 10.1007/s00267-003-9124-3

Longleaf Pine: A Sustainable Approach for Increasing Terrestrial Carbon in the Southern United States

JOHN S. KUSH*
RALPH S. MELDAHL
School of Forestry and Wildlife Sciences
Auburn University
108 M. White Smith Hall
Auburn, Alabama 36849, USA

CHARLES K. MCMAHON
WILLIAM D. BOYER
Southern Research Station
USDA Forest Service
520 Devall Drive
Auburn, Alabama 36849, USA

ABSTRACT / Natural communities dominated by longleaf pine (*Pinus palustris* Mill.) once covered an estimated two thirds of the forested area in the southeastern United States. Today, less than 1.2 million ha remain. However, over the past 10–15 years, public land managers have begun to restore many longleaf pine forests. More recently incentive programs have prompted reforestation and afforestation programs on nonindustrial private lands. These activities have been facilitated by improved longleaf regeneration technology and by expanded educational and outreach efforts. In the South, there is also a growing trend towards longer rotations due to changes in wood/fiber markets and prices. These trends suggest a new strategy to increase terrestrial carbon storage in the southeastern United States in a way that provides many simultaneous ecological and economic benefits. For example, longleaf pine is a long-lived species with a low mortality rate. Among the southern pine species, it has a high specific gravity and can tolerate a very wide variety of habitats. Longleaf pine is better able to sustain growth at older ages (over 150 years) and is tolerant to fire and many insects and diseases. Recent research also indicates that longleaf pine managed for longer rotations outperforms other commercial southern pine species on most sites and might better adapt to future climate scenarios with higher temperatures and higher atmospheric CO_2 levels. Moreover, the higher-value, longer-lasting wood products derived from longleaf pine forests will continue to store carbon over long time periods.

Atmospheric carbon dioxide (CO_2) levels have been increasing steadily since the beginning of the industrial revolution and rising dramatically over the past several decades. As a greenhouse gas, there are concerns that increasing CO_2 levels will cause damaging changes in global climate. Worldwide, there has been increasing attention given to reducing atmospheric CO_2 levels by increasing carbon sequestration and storage, in forested ecosystems. Birdsey and Heath (1997) estimated that US forests have sequestered enough carbon over the past 40 years to offset approximately 25% of CO_2 emissions in the United States. According to this report, managed southern forests played a large role in this offset.

KEY WORDS: Longleaf pine; *Pinus palustris*; Carbon sequestration; Carbon storage; US southern forests; Carbon sink

Published online December 4, 2003.

*Author to whom correspondence should be addressed, *email:* kushjoh@auburn.edu

If southern forests are going to play an expanded role in the sequestration and storage of atmospheric carbon, many questions must be addressed such as: What species are optimal for carbon storage? What management practices and rotation options favor long-term carbon storage? What are the impacts of a regional carbon storage strategy on biodiversity and soil quality? Will the process be sustainable and socially acceptable? In this paper, we propose a regional carbon sequestration and storage approach utilizing longleaf pine (*Pinus palustris* Mill.) as the preferred commercial southern pine species [the other species being loblolly pine (*P. taeda* L.), shortleaf pine (*P. echinata* Mill.), and slash pine (*P. elliottii* Engelm.)] to use in the southeastern United States, especially in the Atlantic and Gulf Coast coastal plain regions. This approach is based on the bringing together of several factors related to:

1 the biology and ecology of longleaf pine,
2 research findings from long-term studies,
3 longleaf pine products and utilization, and
4 recent developments in longleaf pine management.

Background

Prior to the arrival of settlers to the United States, natural communities dominated by longleaf pine and maintained by periodic fire occurred throughout most of the southern Atlantic and Gulf Coastal Plains. These communities once covered an estimated 24–36 million ha, or two thirds of the area in the Southeast (Vance 1895, Chapman 1932, Frost 1993). These forests were described as open and parklike, with a largely monospecific overstory and the most species-rich understory in temperate North America (Peet and Allard 1993). The open canopy was not due to an arid climate or soil infertility, but rather the frequent lightning and aboriginal fires that killed less fire-tolerant vegetation, leaving longleaf pine and its herbaceous understory to thrive.

Exploitation of longleaf pine-dominated forests has led to a steady decline of its acreage. By 1935, only 8 million ha were left, declining to 4.8 million ha by 1955. Noss (1989) noted that longleaf pine comprised 40.4% of the southern coastal plain in presettlement times. Today, that number has decreased to 0.7%.

According to Outcalt and Sheffield (1996), longleaf pine stands cover some 1.2 million widely distributed and fragmented hectares in the South of which 1.1 million ha (91%) support natural stands and contain 94% of the species' growing stock volume. These natural stands are a very important source of high-value wood products, provide unique multiple-use benefits, maintain biological diversity and supply necessary habitat for several rare and endangered species. The significant loss of longleaf pine acreage did not change its regional distribution. Because of its broad geographic range and adaptation to a wide variety of habitats, longleaf pine should be well suited to adjust to possible changes in climate.

Johnsen and others (2001) reported that the amount of carbon sequestered and stored by managed forests is determined by three factors: increases due to land-use changes and increased productivity of managed forests; carbon remaining in the soil at the end of a rotation; and the carbon stored in products made from the harvested wood.

Conceptually, one can develop several approaches to increase terrestrial carbon in the southeastern region of the United States. Some approaches might be based on restoring or expanding forest types (or forest type groups) that are well adapted to specific site conditions and physiographic features, while other approaches may incorporate new intensive plantation management practices or involve genetic modification and manipulation. The approach we propose may seem counterintuitive to some observers, given the dramatic decline in the longleaf pine ecosystem over the last century coupled with the long-held beliefs that longleaf pine is "hard to regenerate, and slow to grow." While these beliefs may have been partially grounded in truth in the past, new technology related to seeds (Barnett and McGilvray 2002), seedlings (Barnett and McGilvray 1997, planting techniques (Hainds 2003), regeneration and management alternatives (Franklin 1997, Earley 1997), conservation incentives (Johnson 2001) and land use policies (Costa 1999) can greatly alleviate these concerns. In addition, recent outreach, educational and extension programs by the Longleaf Alliance (Gjerstad and Johnson 1999) have been effective in communicating new information and technology and new management options to landowners and managers in the former longleaf range. Alternative revenue streams from nontraditional forest values such as wildlife and hunting leases, pine straw harvesting, and the current potential for "carbon credits" are providing new opportunities for private owners for managing longleaf pine over longer rotations.

The Biology and Ecology of Longleaf Pine

Life-span

One of the major ways to sequester and store carbon is to tie it up for as long as possible in long-lived trees. Among southern tree species, longleaf pine may outlive any other species except for bald cypress. While the native longleaf pine forest contained stands covering a wide range of ages, a substantial portion of the old-growth timber appeared to be in the 200- to 300-year-old age range when it was logged. Longleaf pine in excess of 450 years in age has been reported (Platt and others 1988), thus a maximum biological age of over 500 years is not unreasonable. However, due to the constant hazards of lightning and wind, very few trees are ever likely to reach this biological potential.

Not only does longleaf pine outlive the other southern pines by 100–300 years, it continues to grow and respond to release even at older ages. In one of the first studies to examine the growth of longleaf pine, Chapman (1909) examined the timber tallies of 162 ha of pure even-aged old-growth longleaf pine stands in Tyler County, Texas, USA. He reported that trees per hectare would drop from 148 to 27 going from a stand 100 years old to 320 years old with average diameter at breast height (DBH) increasing from 35.6 to 75 cm. Mean annual growth was at a maximum at 110 years. Longleaf pine did not increase much in yield per hectare after 120 years, with the disappearance of trees through attrition (decay, fire, etc.) offsetting the increase in size.

The increase in actual quantity was very slow up to 250 years, and then it slowly diminished. Medium- to well-stocked even-aged longleaf pine stands over a range of sites should reach a steady-state condition (growth and mortality approximately in balance) at about 120 years. Mortality could be harvested and converted into high-quality products in the proposed system.

More recently, West and others (1993) reported on increases in annual increments of all age classes for trees from 100 to nearly 400 years old. This increase, beginning in approximately 1950 and continuing to the present, resulted in an average annual ring increment approximately 40% greater in 1987 than 1950. When compared with expected annual increment, the increase for 100- to 150-year-old trees is approximately 45%, while the increase for 200- to 400-year-old trees is approximately 35%. They could not explain the increased growth based on disturbance, stand history, or trends in precipitation and temperature.

Site Adaptations

Longleaf pine is not only among the longest-living of the southern species, but it is found growing on all but the wettest sites across the Southeast. Two authors made testament to this fact. Harper (1928) said, "Longleaf pine might have once been the most abundant tree in the United States and was certainly the most abundant tree in Alabama." Chapman (1932) wrote:

> In the longleaf pine type of the south (and nowhere else in North America to the writer's knowledge) fire at frequent but not necessarily annual intervals is as dependable a factor of site as is climate or soil. The conception of a climax type as one which has reached a stage of permanent equilibrium or perfect adaptation to these constant factors of site should include the longleaf pine type of the south, which presents by far the greatest area and most permanent characteristics of any climax to be found in the United States.

Longleaf pine occurs under a variety of environmental conditions. The range of longleaf pine covers a broad arc along the coastal plain and portions of the Piedmont from southern Virginia, south to central Florida, and west to eastern Texas, extending further inland in the Cumberland Plateau and Ridge and Valley physiographic provinces in Alabama and Georgia. Unlike the other southern pines, longleaf pine tolerates a wide variety of habitats. It is found growing on dry mountain slopes and ridges in Alabama and northwest Georgia, on the low, wet flatwoods, as well as the excessively drained sandhills found along the coast and fall line. Longleaf pine forests exist up to an elevation of 580 m above mean sea level, and down to near sea level along the Atlantic Ocean and Gulf of Mexico coastline. Although most often associated with deep (often > 4.7 m) sandy soils, or sandhills, longleaf pine occurs on all but the most inundated soils in the southeastern USA (Wahlenberg 1946).

Natural Resistance to Risks

Comparatively speaking, longleaf pine has a superior natural resistance to fire, insects, diseases, and windthrow from hurricanes that the other southern pines (Wahlenberg 1946). Across much of the Southeast, southern pine beetles [*Dendroctonus frontalis* Zimmermann (Coleoptera: Scolytidae)] have periodically destroyed vast acreages of loblolly pine stands. Littleleaf disease, a disease caused by a complex of factors including the fungus *Phytophthora cinnamomi* Rands, has been a major problem with shortleaf pine. However, where longleaf pine is grown, there are no reports of large acreage losses. Diseases and insects rarely cause mortality of longleaf pine. Longleaf is somewhat resistant to the several species of coleopteran bark beetle (*Denroctonus* and *Ips* spp.), a severe problem for other southeastern USA pine species (Anderson and Doggett 1993). Longleaf is usually less susceptible to infection from fusiform rusts (*Cronartium* spp.) than other southern pines (Walkinshaw and others 1993). Lightning strikes are the primary inciting agent of mortality in longleaf forests (Platt and others 1988, Palik and Pederson 1996). In a more recent study, McNulty (2002) concluded that longleaf pine may be the species to grow in the South where hurricanes can have a major impact, noting its resistance to breakage and uprooting, fire, as well as its natural resistance to insect and disease outbreaks.

Specific Gravity

There is very little difference in the percent carbon found in various tree species; all have approximately 50% carbon on a dry weight basis. However, there are significant differences among tree species in the specific gravity or density of the wood. This is a very important factor in the context of carbon storage since it is directly related to the quality of wood products, product utilization, and related long-term decay rates. It is also very important when comparing the growth rates of tree species using models which report productivity in volumetric terms (i.e., cubic meters per hectare).

There can be wide variations in the specific gravity of a tree species based on age and site location. From a large sample of age classes and site locations, the specific gravity (based on green volume and oven dried weight) of longleaf pine averaged 8%–12% higher than the other commercial southern pine species (Koch

1972). The specific gravity of longleaf pine averaged 0.57, with a range of 0.40–0.75; slash pine (var. *elliottii*) averaged 0.53, range 0.41–0.70; loblolly pine averaged 0.51, range 0.38–0.68; and shortleaf pine averaged 0.52, range 0.37–0.72. Zobel and others (1972) also reported that when grown on the same site, longleaf pine nearly always produced wood with a higher specific gravity than either slash or loblolly pine.

Native Species/Ecosystem Benefits

Thus far, the discussion has been about the tree and why its biology makes it a preferred southern pine species to grow for carbon storage. Another reason for growing longleaf pine would be the potential ecological benefits derived from the important plant and animal communities associated with longleaf pine ecosystems. As noted earlier, longleaf pine forest acreage has plummeted to less than 3% of its former range. Continuing pressures from commercial development and exploitation led the National Biological Service to list longleaf pine forests as the second most endangered ecosystem in the United States, second only to the south Florida landscape (Noss and others 1995). A fire-maintained longleaf pine ecosystem is among the most species-rich outside of the tropics. A mesic longleaf woodland may contain 140 vascular species per 1000 sq m, the largest values reported for the temperate Western Hemisphere (Peet and Allard 1993).

With the precipitous decline of the longleaf pine forest, the associated flora and fauna have also suffered. Twenty-seven plant and animal species associated with the longleaf forest have been listed as federally threatened or endangered by the US Fish and Wildlife Service, including such key wildlife species as the red-cockaded woodpecker, gopher tortoise, indigo snake, and southern fox squirrel, with an additional 99 candidate species (Noss and others 1995). Hardin and White (1989) highlighted an additional 191 associated plant species of the longleaf pine forest that are of special management concern.

Research Findings from Long-Term Studies

Several studies indicate that for longer rotations (especially on sites with low to marginal site quality); longleaf pine will outperform the other three major commercial southern pines. In the past, forest managers generally did not seriously consider longleaf pine in their management plans because of poor survival and the slow early growth (during longleaf's grass-stage period) compared to slash and loblolly pines, which do not have a grass-stage. However, as more data from long-term studies emerge there is additional evidence that the long-term growth rate of longleaf pine is equal or superior to other southern pines and that it produces a higher quality, longer lasting product mix. In this paper, we briefly summarize four long-term studies that support the observation.

Schmidtling (1985) Study

In a side-by-side comparison with loblolly and slash pine, longleaf pine grew as well as, or better than, loblolly or slash once it had emerged from the grass stage. A reexamination of that study at 39 years (Harris and others 2001) found that longleaf pine had higher survival, total basal area, and volume when compared with either slash or loblolly pine. In addition, more than 70% percent of the longleaf pine could be classified as having a quality to make them into utility poles compared to 12% for slash pine and 8% of the loblolly pine.

Shoulders (1985) Study

The results of 35 site-species trials in Louisiana and Mississippi were reexamined: (1) to learn if early emergence of well-stocked longleaf plantations from the grass stage would make them competitive in terms of growth and yield with the other major southern pines on a given site, and (2) because of concerns in the early 1980s that yields from slash and loblolly pine plantations would be substantially reduced due to fusiform rust. While there were certain site conditions where the other southern pines had more volume at the end of 20 years, longleaf pine stand basal area equaled or exceeded that of other species from age 15 onward. The conclusion was that longleaf pine was as potentially productive as the other southern pine species under a wide variety of site conditions if the problems of poor planting survival and brownspot needle blight (*Mycosphaerella dearnessii* Barr.) could be overcome.

Outcalt (1993) Study

Sandhills occupy significant acreage of the southeastern United States. They are typified by soils that are infertile and droughty. Many of these soils are quartz sands from a few to more than 20 feet deep. Water retention and nutrient content are low due to the low organic matter and clay content. Most of these sites were originally dominated by longleaf pine. However, following the removal of longleaf in the early 1990s, most of these sites were taken over by scrub oak.

Many of these sites were planted to sand pine, either Choctawhatchee sand pine (*Pinus clausa* var. *immuginata* D.B. Ward) or Ocala sand pine (*Pinus clausa* var. *clausa* D.B. Ward). The growth of these two species was compared to longleaf, slash, and loblolly pines after

28 years on deep sands in South Carolina and Georgia, USA. If the goal was to maximize yield for pulpwood rotations of 25–35 years, then Choctawhatchee sand pine was recommended for planting on these sandhill sites. However, longleaf pine has been growing as fast as Choctawhatchee sand pine since the age of 15, and if longer rotations are desired, then longleaf pine was recommended as the alternative species to plant.

Hoover (2000) Study

As part of the Northern Global Change Program, a project was conducted to estimate current carbon storage on selected Department of Defense installations and to evaluate the future carbon sequestration potential of these lands under different forest management scenarios. Multiple stand growth simulations were run on a 40-ha stand with a rotation age of 40 years. The parameters tested were site index, initial stocking level and survivorship at 10 years. In nearly all cases, the simulations indicated that longleaf pine would store more carbon then the other three major southern pine species, given the same starting conditions. Results from the old-field longleaf pine plantation simulator indicated there would be carbon gains due to increased stocking toward the end of the simulation period, when the trees were putting on volume rapidly and continued to do so beyond the 40-year rotation. Holding stocking levels constant and varying site index, a rotation of longleaf pine on a high-quality site stored more carbon than any other species investigated.

These studies have shown that under longer rotations, longleaf pine can compete with the other commercial southern pines, and in many cases, out live and out grow them. In addition to these research findings, a few studies have addressed the topic of longleaf pine growth given potential changes in climatic conditions. Devall and Parresol (1998) suggest that loblolly pine may give way to longleaf pine as sites become hotter and drier. Pritchard and others (2001) indicated that elevated CO_2 increased total aboveground biomass by 20% and belowground increased root biomass of longleaf pine by 62%. With increasing CO_2 levels, the increased root biomass of longleaf pine should give it an advantage over competitors. In addition to the previously cited study by West and others (1993) about recent growth increases in old-growth longleaf pine, Boyer (2001) observed a site index increase of more than 17 feet between second- and third-growth longleaf pine stands growing on the same sites. In a direct comparison study, a site index for second growth averaged 65 feet while third growth averaged 83 feet. The reasons for this large increase in site quality are unknown, but since the soils are the same, some change in climate, including increased levels of CO_2 may be suspected.

Longleaf Pine Products and Utilization

As early as the late 1800s, the wood of longleaf pine was reported as heavier as and stronger than that of any other pine (Mohr 1897). Due to its excellent wood quality for construction, it was estimated that nearly onethird of all lumber manufactured in the South at that time was longleaf pine. The wood was unsurpassed for posts, pilings, and joists, especially in bridge, railroad trestle, warehouse, and factory construction. In the early years, the untreated heartwood was widely used for railroad ties due to its natural resistance to termites and rot.

Longleaf pine was an important part of the Southern natural heritage and culture. Longleaf pine was certainly the tree that built the South and, to a certain extent, built this country. It has been estimated that three fourths of the first settlers in the Carolinas, Georgia and Florida built 75% of their houses and commercial structures from longleaf pine. Most of the wharves from New York to New Orleans were constructed with longleaf pine. In fact, the keel of the American Revolutionary warship, *U.S.S. Constitution,* was built of longleaf pine. As early as 1608, longleaf pine tar and pitch extracts were exported from Virginia. Harper (1928) wrote "Longleaf pine had more uses than any other tree in North America, if not the whole world..." Among the reasons for this is the fact that longleaf pine has better strength and product utility when compared to the other southern pines. Longleaf pine is heavier, stronger, stiffer, harder, and moderately high in shock resistance. Industry will single out longleaf pine for its lumber because of the denser growth rings and the good mechanical properties it has due to the clear, straighter-grained wood it produces.

Thus, if forest management is going to be practiced and trees are cut, then longleaf pine is a good tree species for the purpose of long-term carbon storage. This is based on the durable nature of the products produced and how they can be utilized for centuries, as compared to the pulp and fiber products derived from short-rotation forest management, which return carbon to the atmosphere over a relatively short period.

One of the many unique characteristics that make longleaf pine superior to the other southern pines for long-term storage is its growth form. The natural form is characterized by straight, knot-free boles. Therefore, a stand of longleaf pine produces a greater percentage of high-valued poles than other southern pine species; as much as 75% percent of a longleaf pine stand that has been managed for pole growth according to Williston and Screpetis (1975). The percentage is considerably less for loblolly or slash pine. This has a potential financial advantage for landowners and industry because poles may be twice as valuable as sawtimber. In addition, poles, when treated to resist decay, represent a source of long-term storage for carbon. In addition to poles, longleaf pine produces high-quality products for pillings, posts, and housing materials. The inherent strength and structural properties of longleaf pine make it the preferred species for the manufacturing of structural glue-laminated beams and timber bridge components.

Many buildings in the United States and certainly most in the South built in the early 1800s were built of longleaf pine. Today, many of the timbers left from buildings constructed long ago are being recycled for flooring, paneling, molding, and beams. Carbon that was stored in longleaf pine when trees were cut in the early 1800s is still being stored today in these recycled materials. In addition, old-growth longleaf pine logs cut around 1900 are also being recovered from rivers and waterways and processed into high-quality products.

Recent Trends Favorable for Longleaf Pine Management

The recent Southern Forest Resource Assessment (Wear and Greis 2002) forecasts pine plantations to rise in the South by 67% by the year 2040, rising from 12 million ha in 1999 to 22 million ha in 2040. Most gains are expected to come from converted agricultural fields. Many questions are now being raised about the impacts of this forecast on regional biodiversity based on the assumption that most of the plantations would be managed intensively for maximum volume. If carbon credits were to play a role in a private landowner's decision on what pine trees to plant, the longleaf pine strategy outlined in this paper would compete favorably as a sustainable approach that would provide both economic and ecological benefits. There are already many indications that the decline of this species has been reversed on public lands. Private lands seem to be headed in the same direction because of the availability of incentives and related outreach and extension efforts by state agencies and the partners of the Longleaf Alliance. At the same time, there are groups in the southeast forming to help landowners capitalize on carbon credits derived from forestry programs.

Public Land Trends

Restoration of the longleaf pine ecosystem is now a goal on much of the public land in the southeastern United States. The national forests (NFs) that lie in the former range of longleaf pine are making restoration of this ecosystem a high priority. Jeffers and Tomczak (2003) report a 26% increase in longleaf pine hectares on lands managed by the NFs in the period 1988–2002. The restoration on these lands will be a slow and continuing process involving both natural and artificial regeneration, the removal of off-site pines, and expanded prescribed burning programs. The target goal, or desired future condition is 504,000 ha, an 86% increase compared to 1988 targets. Similar restoration activities are also occurring on other large parcels of public lands managed by the Department of Defense, the US Fish and Wildlife Service, and several southeastern states.

Private Land Trends

The incentives for planting longleaf pine on private land in the federally sponsored Conservation Reserve Program (CRP) resulted in approximately 121,000 ha being planted on mostly agriculture lands in the two years the program was available (1999–2000). About 50 million longleaf seedlings were planted under this program in 2000, nearly half of the total grown and sold (Johnson 2001). By itself, this number may seem insignificant when compared to other commercial pine species such as loblolly pine. However, it represents a sharp reversal of the precipitous decline in longleaf pine hectares that had been occurring on private lands. For example, regional survey results reported by Kelly and Bechtold (1990) and Outcalt and Sheffield (1996), indicate that private lands accounted for approximately 95% of the longleaf hectares lost region wide in the 10-year period between the mid-1980s and the mid-1990s.

Other federal/state stewardship incentive programs are available. One, known as Safe Harbor, is successfully addressing the fears of private owners that long-rotation longleaf pine management might lead to habitat suitable for endangered species and thereby result in locking up the lands from harvesting and further development. Safe Harbor programs are designed to provide private landowners with voluntary, no-cost alternatives to address this concern. Many successful sign-ups have occurred, especially in the sandhills region of North and South Carolina (Costa 1999). Several other states are developing similar programs.

Sustaining the interest of the nonindustrial private forest landowners in longleaf pine management must ultimately overcome the cash flow problem associated with longer rotations. Several surveys have shown that most of these nonindustrial private owners are not seeking to maximize growth and yield but are interested in a range of stewardship objectives that integrate commodity (forest products) values with noncommodity values (wildlife, water, aesthetics etc.). Managing for value, not volume, has become the new paradigm for these owners. The cash flow problem is being partially addressed by the promotion of alternative revenue streams derived from nontraditional forest products such as pine straw and wildlife or hunting leases. If a new revenue stream related to carbon credits became available, it would greatly help to offset this problem and produce many social and ecological benefits.

Demand for southern pine pulpwood derived from short-rotation forest management has dropped dramatically in recent years, with a corresponding drop in prices. The drop in demand is a combination of increased use of recycled fiber, increased imports, a shift of production capacity to foreign lands with fewer environmental constraints, and the increased efficiencies of domestic mills (Shorter 2002). These trends have turned some large industrial forestry corporations and associated investment management firms toward a strategy of growing pine trees for lumber rather than for pulpwood. Since fast grown trees do not have the best quality for lumber, managing for mature wood grown over longer rotations is being carefully considered. The new strategy for longer rotations embraces a vision to plan for maximum economic return rather than maximum volume and includes consideration of potential income derived from carbon credits. Large forest product companies, associated timberland investment management institutions, the electric power industry, and other "carbon intensive firms" have begun to examine carbon sequestration programs aimed at restoring forestlands and capturing the resulting environmental and economic benefits (Totten 1999).

Emerging Markets for Carbon Credits from Southeastern Forests

Organizations such as the Carbon Fund (http://www.thecarbonfund.org), based in Stoneville, Mississippi, USA, are financing and promoting the protection, restoration, and enhancement of forests all over the world through carbon sequestration programs. One of the primary purposes of the Carbon Fund is to assist farmers and landowners in pooling and marketing their carbon credits. The current focus is on bottomland hardwood programs but also includes plans for lands in the longleaf range in the coastal plain and flatwood regions of the southeast. The nonprofit UtilTree Carbon Company consists of 40 utilities that sponsor a diverse mix of rural tree planting, forest preservation, forest management, and research efforts at both domestic (Arkansas, Louisiana, Mississippi, and Oregon) and international sites (www.eei.org/issues/enviro/g_climate/utilitree.pdf). The Winrock International Ecosystems Services Group has recently prepared an assessment of the carbon sequestration potential of longleaf pine in Georgia for the Oglethorpe Power Company. They concluded a restoration program would be best aimed at marginal farmlands with low opportunity costs, particularly at sites removed from the path of urbanization (Shoch and others 2002).

Trends in Longleaf Pine Outreach and Extension Programs

The Longleaf Alliance (http://www.longleafalliance.org/), a university-based organization established in 1995, is helping to support the region-wide recovery of longleaf pine, especially on private lands. The alliance is a partnership of private landowners, forest industries, state and federal agencies, conservation groups, researchers, and others interested in managing and restoring longleaf pine forests for their ecological and economic benefits. By emphasizing both the economic and ecological value of the longleaf resource, the Longleaf Alliance now leads a region-wide groundswell of interest in this ecosystem. The alliance serves as a clearinghouse for information on regenerating, restoring, and managing longleaf pine; provides networking opportunities for members to connect with other landowners, managers, and researchers with similar interest and problems; and coordinates technical meetings and educational seminars. In addition, the alliance maintains and constantly updates databases of current longleaf related information, seedling nurseries, wildlife and forestry consultants, and pertinent demonstration sites. Numerous publications are available including conference proceedings, a landowner's guide to longleaf management, research notes, and newsletters. The alliance partners are careful to point out that the push to restore longleaf pine is framed with reasonable and realistic goals: to halt and reverse the decline in the forest type; to restore health to existing ecosystems; and to provide technical assistance to managers and landowners who desire to initiate restoration, reforestation, and afforestation programs.

Summary and Conclusions

Over the past 10–15 years, public land managers have begun to restore many degraded longleaf pine forests and, more recently, incentive programs have prompted longleaf pine reforestation and afforestation programs on nonindustrial private lands. These activities have been facilitated by improved seed, seedling, and planting technology; new regeneration and management alternatives; and by expanded educational and outreach efforts.

In the South, there is a growing trend in forestry towards longer rotations due to changes in wood/fiber markets and prices. These trends suggest a new opportunity to increase terrestrial carbon storage in the southeastern United States in a way that provides many ecological and economic cobenefits. We suggest that on many sites in the Gulf and Atlantic coastal plain region of the southeastern United States, longleaf pine is the optimal choice among the commercial pine species to capitalize on the economic and ecological benefits, especially if carbon credits are factored into the decision process.

For example, longleaf pine is a long-lived species with a low mortality rate. Among the southern pine species, it has a high specific gravity and can tolerate a very wide variety of habitats. Longleaf pine is better able to sustain growth at older ages (over 150 years) and is tolerant to fire and many insects and diseases. Recent research clearly indicates that longleaf pine managed for longer rotations outperforms other commercial southern pine species on most forest sites. There are also some early indications that longleaf pine might better tolerate future warmer climate scenarios. Moreover, the higher value longer lasting wood products derived from longleaf pine forests will continue to store carbon over long time periods.

We fully understand that the restoration of a fully functioning longleaf ecosystem appeals to landowners in varying degrees. We also recognize that an intact longleaf forest ecosystem is not likely ever again to dominate the Southern landscape. However, if a voluntary choice is to be made on what tree is best adapted to and suited for growing on sites in the former longleaf range to provide a sustainable combination of ecological and economic values, we would argue that tree would be longleaf pine. The argument is strengthened when the trends toward longer rotations and the added benefits of carbon credits are factored into the decision process.

Longleaf pine is not a very demanding species compared to loblolly and slash pine, and its growth and yield is much less affected by changes site quality. Factors other than site quality, as traditionally defined, may play significant roles in the growth of longleaf pine.

References

Anderson, R. F., and C. A. Doggett. 1993. Host preference of southern pine beetle in North Carolina. Forestry Note No. 66, North Carolina Division of Forest Resources.

Barnett, J. P. and McGilvray, J. M. 1997. Practical guidelines for producing longleaf pine in containers. General Technical Report SRS-14. USDA Forest Service, Asheville, North Carolina.

Barnett, J. P. and McGilvray, J. M. 2002. Guidelines for producing quality longleaf pine seeds. General Technical Report SRS-052. USDA Forest Service, Asheville, North Carolina.

Birdsey, R. A., and L. S. Heath. 1997. The forest carbon budget of the United States. Pages 81–85 *in* R. Birdsey, R. Mickler, D. Sandberg, R. Tinus, J. Zerbe, and K. O'Brian. Eds, USDA Forest Service Global Change Research program highlights: 1991–1995. General Technical Report NE-237. USDA Forest Service, Washington, DC.

Boyer, W. D. 2001. A generational change in site index for naturally established longleaf pine on a southern Alabama Coastal Plain site. *Southern Journal of Applied Forestry* 25(2):88–92.

Chapman, H. H. 1909. An experiment in logging longleaf pine. *Forest Quarterly* 7:385–395.

Chapman, H. H. 1932. Is the longleaf type a climax?. *Ecology* 13:328–334.

Costa, R. 1999. Safe Harbor: A private lands conservation strategy for longleaf pine habitat and red-cockaded woodpeckers. Pages 42–44 *in* J. S. Kush Eds, Proceedings of the second Longleaf Alliance conference. Longleaf Alliance Report No. 4. .

Devall, M. S., and B. R. Parresol. 1998. Effects of global climate change on biodiversity in forests of the southern United States. Pages 663–682 *in* R. A. Mickler, and S. Fox. Eds, The productivity and sustainability of southern forest ecosystems in a changing environment, Mickler and S. Fox. Springer-Verlag, New York.

Earley, L. S. (ed.). 1997. A working forest: a landowners guide for growing longleaf pine in the Carolina Sandhills. Sandhills Area Land Trust, Southern Pines, North Carolina, 32 pp.

Franklin, R. 1997. Stewardship of longleaf pine forests: a guide for landowners. Longleaf Alliance Report No. 2, 44 pp.

Frost, C. C. 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. *Tall Timbers Fire Ecology Conference Proceedings* 18:17–43.

Gjerstad, D., and E. Johnson. 1999. The Longleaf Alliance: a regional longleaf pine recovery effort. *Alabama's Treasured Forests* 18(4):22, 27.

Hainds, M. 2003. Determining the correct planting depth for container-grown longleaf pine seedlings. Proceedings of the fourth Longleaf Alliance regional conference. Longleaf Alliance Report No. 6. (in press)

Hardin, E. D., and D. L. White. 1989. Rare vascular plant taxa associated with wiregrass (*Aristida stricta*) in the southeastern United States. *Natural Areas Journal* 9:234–245.

Harper, R. M. 1928. Economic botany of Alabama. Monograph 9. Part 2. Alabama Geological Survey, Tuscaloosa, Alabama.

Harris, A. H., J. S. Kush, R. S. Meldahl, and J. M. Varner. 2001. And the winner is...longleaf pine: response of planted pines to various cultural treatments 39 years later. Pages

129–131 *in* J. S. Kush Eds, Proceedings of the third Longleaf Alliance regional conference: Longleaf Alliance Report No. 5.

Hoover, C. M. 2000. Carbon sequestration on Department of Defense lands: executive summary. Retrieved October 9, 2000, from Defense Environmental Network and Information eXchange website: https://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/CarbonReport/carbonreport.html.

Jeffers, R. M., and D. J. Tomczak. 2003. Longleaf pine ecosystem restoration on the national forests and Savanna River Institute: 1988–2002. Proceedings of the fourth Longleaf Alliance regional conference. Longleaf Alliance Report No. 6. (in press)

Johnsen, K., D. Wear, R. Oren, R. O. Teskey, F. Sanchez, R. Will, J. Butnor, D. Markewitz, D. Richter, T. Rials, H. L. Allen, J. Seiler, D. Ellsworth, C. Maier, G. Katul, and P. M. Dougherty. 2001. Carbon sequestration and southern pine forests. *Journal of Forestry* 99(4):14–21.

Johnson, E. 2001. Comments from a co-director. The Longleaf Alliance Newsletter, vol 5, No. 3 September 2001. The Longleaf Alliance, Solon Dixon Forestry Education Center, Andalusia, Alabama. p. 1.

Kelly, J. F., and W. A. Bechtold. 1990. The longleaf pine resource. Pages 11–12 *in* R. M. Farrar, Jr. (ed.), Proceedings of the symposium on the management of longleaf pine. General Technical Report SO-75. USDA Forest Service, New Orleans, Louisiana.

Koch, P. 1972. Utilization of the southern pines: vol. I: the raw material. USDA Forest Service, Agricultural Handbook No. 420.

McNulty, S. G. 2002. Hurricane impacts on US forest carbon sequestration. *Environmental Pollution* 116(2002):S17–S24.

Mohr, C. T. 1897. The timber pines of the southern United States. USDA Division of Forestry Bulletin 13, Washington, DC.

Noss, R. F. 1989. Longleaf pine and wiregrass: keystone components of an endangered ecosystem. *Natural Areas Journal* 9(4):234–235.

Noss, R. F., E. T. LaRoe, and J. M. Scott. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. U.S. Department of Interior, National Biological Service, Biological Report 28, 58 pp.

Outcalt, K. W. 1993. Southern pines performance on sandhills sites in Georgia and South Carolina. *Southern Journal of Applied Forestry* 17(2):100–102.

Outcalt, K. W. and R. M. Sheffield. 1996. The longleaf pine forest: trends and current conditions. Resource Bulletin SRS-9. USDA Forest Service, Asheville, North Carolina.

Palik, B. J., and N. Pederson. 1996. Overstory mortality and canopy disturbances in longleaf pine ecosystems. *Canadian Journal of Forest Research* 26:2035–2047.

Peet, R. K., and D. J. Allard. 1993. Longleaf pine vegetation of the southern Atlantic and eastern Gulf Coast regions: a preliminary classification. *Timbers Fire Ecology Conference Proceedings* 18:45–81.

Platt, W. J., G. W. Evans, and S. L. Rathbun. 1988. The population dynamics of a long-lived conifer. *(Pinus palustris). The American Naturalist* 131(4):491–525.

Pritchard, S. G., M. A. Davis, R. J. Mitchell, A. S. Prior, D. L. Boykin, H. H. Rogers, and G. B. Runion. 2001. Root dynamics in an artificially constructed regenerating longleaf pine ecosystem are affected by atmospheric CO_2.. *Environmental and Experimental Botany* 46:35–69.

Schmidtling, R. C. 1987. Relative performance of longleaf pine compared to loblolly and slash pines under different levels of intensive culture. Pages 395–400 *in* D. R. Phillips Eds, Proceedings of the fourth biennial southern silvicultural research conference. General Technical Report SE-42. USDA Forest Service, Asheville, North Carolina.

Shoch, D., S. Brown, M. Delany and R. Broadwell. 2002. An assessment of carbon sequestration potential of longleaf pine restoration and conservation in Georgia. Winrock International Ecosystem Services Group, report prepared for Oglethorp Power Company. Winrock International, Washington, DC, 32 pp.

Shoulders, E. 1985. The case for planting longleaf pine. Pages 255–260 *in* E. Shoulders Eds, Proceedings of the third biennial southern silvicultural research conference. General Technical Report SO-54. USDA Forest Service, New Orleans, Louisiana.

Shorter, W. W. 2002. Pulpwood demand in decline; lumber may offer better potential. *Forest Landowner* July/August:39.

Totten, M. 1999. Getting it right: emerging markets for storing carbon in forests. World Resources Institute, Washington, DC, 49 pp.

Vance, L. J. 1895. The future of the longleaf pine belt. *Garden and Forest* 8:278–279.

Wahlenberg, W. G. 1946. Longleaf pine: its use, ecology, regeneration, protection, and management. Charles Lathrop Pack Forestry Foundation and USDA, Forest Service. Washington, DC, 429 pp.

Walkinshaw, C. H., R. L. Bryant, and J. P. Barnett. 1993. Comparative fusiform rust severity in loblolly, longleaf, and slash pines. Pages 293–297 *in* J. C. Brissette Eds, Proceedings of the seventh biennial southern silvicultural research conference. General Technical Report SO-93. USDA Forest Service, New Orleans, Louisiana.

Wear, D. N. and J. G. Greis (eds.). 2002. Southern forest resource assessment. General Technical Report SRS-53, USDA Forest Service, Southern Research Station, Asheville, North Carolina, 635 pp.

West, D. C., T. W. Doyle, M. L. Tharp, J. J. Beauchamp, W. J. Platt, and D. J. Downing. 1993. Recent growth increases in old-growth longleaf pine. *Canadian Journal of Forest Research* 23(5):846–853.

Williston, H. M. and G. Screpetis. 1975. Managing For poles and piling: why and how. Southeastern area state and private forestry. USDA Forest Service, Atlanta, Georgia, 12 pp.

Zobel, B. J., R. C. Kellison, M. F. Matthias, and A. V. Hatcher. 1972. Wood density of the southern pines. Technical Bulletin No 208. North Carolina State University, North Carolina Agricultural Experiment Station, Raleigh, North Carolina, 56 pp.