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Forest Ecology and Management 222 (2006) 202–210

Forest Ecology and Management

www.elsevier.com/locate/foreco

Using natural stand development patterns in artificial mixtures: A case study with cherrybark oak and sweetgum in east-central Mississippi, USA

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Received 18 January 2005; received in revised form 28 September 2005; accepted 30 September 2005

Abstract

Results from a long-term planted mixture of cherrybark oak (*Quercus pagoda* Raf.) and sweetgum (*Liquidambar styraciflua* L.) showed sweetgum taller in height and larger in diameter than cherrybark oak early in plantation development. By age 17 years, cherrybark oak was similar in height and diameter with sweetgum and by age 21 years was taller in height and larger in diameter than sweetgum depending on the spacing arrangement. The ascendance of cherrybark oak above sweetgum in an intimate plantation mixture confirms results from a stand reconstruction study of cherrybark oak and sweetgum development in natural stands.

Afforestation of abandoned agricultural fields and pastures in the Lower Mississippi Alluvial Valley (LMAV) has received much attention in the past 20 years. A common afforestation prescription is to plant oaks on a 3.7 m × 3.7 m spacing. Recently, concern has been expressed about planting only oaks (767 seedlings ha^{-1}) and the resulting effects of early intra-specific competition following canopy closure. Recommendations have included planting a greater number of species in intimate mixtures, but little is known about how such stands would develop. Establishment of mixed-species hardwood plantations in the LMAV should be based on known stand development patterns, whether from other plantation trials or documented patterns in natural stands.

Published by Elsevier B.V.

Keywords: Artificial regeneration; Cherrybark oak; *Liquidambar styraciflua* L.; Mixed-species plantations; Sweetgum; *Quercus pagoda* Raf.; Reconstruction; Stand development patterns

1. Introduction

Afforestation is defined as the establishment of a forest or stand in an area where the preceding vegetation or land use was not forest (Helms, 1998). In the Lower Mississippi Alluvial Valley (LMAV) of the south-central United States, afforestation often involves the establishment of hardwood trees on former agricultural lands on heavy clay soils (Schweitzer and Stanturf, 1997; Stanturf et al., 1998; Schoenholtz et al., 2001). Silvicultural practices include minimal site preparation, either mowing or discing prior to planting, planting 1-0 bareroot oak (*Quercus* spp.) and sweet pecan (*Carya illinoensis* (Wang) K. Koch) for wildlife habitat and timber management objectives, then little to no post-planting release from herbaceous competition (Gardiner et al., 2002). Two problems have evolved based on this ‘‘standard’’ afforestation prescription. First, survival of planted seedlings has oftentimes been less than desired (Schweitzer, 1998). Techniques for establishing bottomland hardwood seedlings have been developed, but on small-scale research plots. Afforestation on large-scale fields, hundreds of hectares in size, has presented a myriad of logistical problems that has affected survival (Gardiner et al., 2002). Greater attention to site preparation, pre-planting seedling care, inspection of ongoing planting operations, and post-planting release operations will increase seedling survival rates (Allen et al., 2001; Gardiner et al., 2002).

A second problem with the ‘‘standard’’ afforestation prescription is the planting of single-species, or in the case

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2005.09.029

of oak mixtures, single-genus stands. Afforestation in the LMAV has focused on planting hard mast (nut producing) species, primarily 1-0 bareroot oak and sweet pecan seedlings, on a 3.7 m × 3.7 m (12 ft × 12 ft) spacing, in single-species stands or blocks of single species within a stand (Stanturf et al., 2000; Schoenholtz et al., 2001; Twedt and Wilson, 2002). These species were favored for their wildlife habitat value and a perceived difficulty in establishment through natural regeneration processes. Light-seeded species, such as green ash (*Fraxinus pennsylvanica* Marsh.), elms (*Ulmus* spp.), American sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), and red maple (*Acer rubrum* L.), would be expected to be naturally dispersed throughout the stand by wind and flooding (Stanturf et al., 1998, 2000). Stanturf et al. (2000) summarized problems with this approach to afforestation in the LMAV: (1) light seeded species are reliably established only within about 100 m from the edge of forests adjacent to abandoned agricultural fields (Allen, 1990, 1997; McCoy et al., 2002); (2) relatively pure oak plantations do not provide diverse vertical structure for many wildlife species (King and Keeland, 1999; Twedt et al., 1999); (3) stocking levels under federal cost-share programs typically do not support commercial timber management, thereby restricting future management options for landowners; (4) the ability to sequester carbon is significantly lower in oak monocultures compared to mixed-species stands.

This second problem, a focus on relatively pure stands, is based on little knowledge concerning development of mixed-species hardwood stands. Recent work in even-aged, mixed-species, natural hardwood stands indicates changes in species dominance occurs over time (Oliver, 1978; Bowling and Kellison, 1983; Clatterbuck et al., 1985; Clatterbuck and Hodges, 1988; Johnson and Krinard, 1988). Species that are dominant during the early years of stand establishment tend to become subordinate to other species, primarily the oaks, during the stem exclusion phase of stand development. For example, Clatterbuck et al. (1985) and Clatterbuck and Hodges (1988) showed, through the use of stand reconstruction techniques, that old fields in minor floodplains in the Gulf Coastal Plain Region would succeed to cherrybark oak–sweetgum (*L. styraciflua* L.) stands. Sweetgum, a shade intolerant, early successional species (Kormanik, 1990) would initially dominate the site. Cherrybark oak (*Quercus pagoda* Raf.) would also become established in these fields but would be inconspicuous due to the high density of sweetgum. Over time, cherrybark oak would emerge above sweetgum to become the dominant canopy overstory species. We hypothesize that stand development patterns found in natural, even-aged mixtures of bottomland species can be emulated in artificial species mixtures. The primary objective of this study was to determine the long-term height and diameter growth patterns in artificial mixtures of cherrybark oak (*Q. pagoda* Raf.) and sweetgum planted at different spacings. A second objective was to determine if results found from stand development in natural stands, especially using the stand reconstruction technique, could be applied to artificial mixtures.

2. Methods

2.1. Study site

The study is located on the Noxubee National Wildlife Refuge in Oktibbeha County, MS, USA (33°18′N, 88°44′W; Fig. 1). The site is a low terrace adjacent to the active floodplain of the Noxubee River. The soil is a Stough fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Fragiaquic Paleudults), which is considered marginal for cherrybark oak ($SI_{50} = 23.2$ m) and sweetgum ($SI_{50} = 21.6$ m) because of the presence of a fragipan (Baker and Broadfoot, 1979). The climate is described as warm and humid (Brent, 1973). Average annual rainfall is 1291 mm, ranging from 156 mm in March to 64 mm in October. Average annual temperature is 18 °C, ranging from 27 °C in July to 8 °C in January. Prior to planting, the site was used for grazing and hay production.

2.2. Planting design and establishment

Three spacing arrangements were used in the study. The first spacing involved planting mixtures of cherrybark oak and sweetgum on a 2.4 m × 2.4 m (8 ft × 8 ft; designated as 2.4 m) spacing. This spacing was the acceptable plantation spacing for trees in the southern United States in the early 1980s. The first row in this spacing arrangement was planted in sweetgum (Fig. 2). Cherrybark oak and sweetgum seedlings were alternated on the second row, and the third row was planted to sweetgum. This spacing arrangement resulted in each cherrybark oak seedling, which was considered plot center, being surrounded by eight sweetgum seedlings. A total of 35 cherrybark oak seedlings and 188 sweetgum seedlings were planted in seven rows (three rows were alternating cherrybark oak and sweetgum seedlings), excluding buffer trees. This spacing arrangement is equivalent to 264 cherrybark oak seedlings ha^{-1} and 1418 sweetgum seedlings ha^{-1}.

The second spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on a 1.5 m × 1.5 m

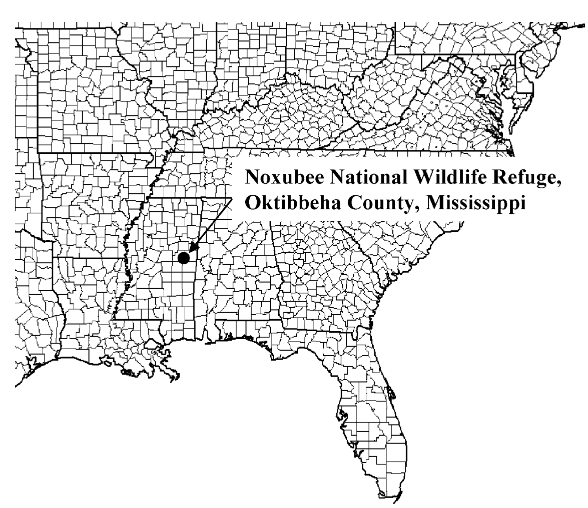

Fig. 1. Location of study site in Oktibbeha County, MS, USA.

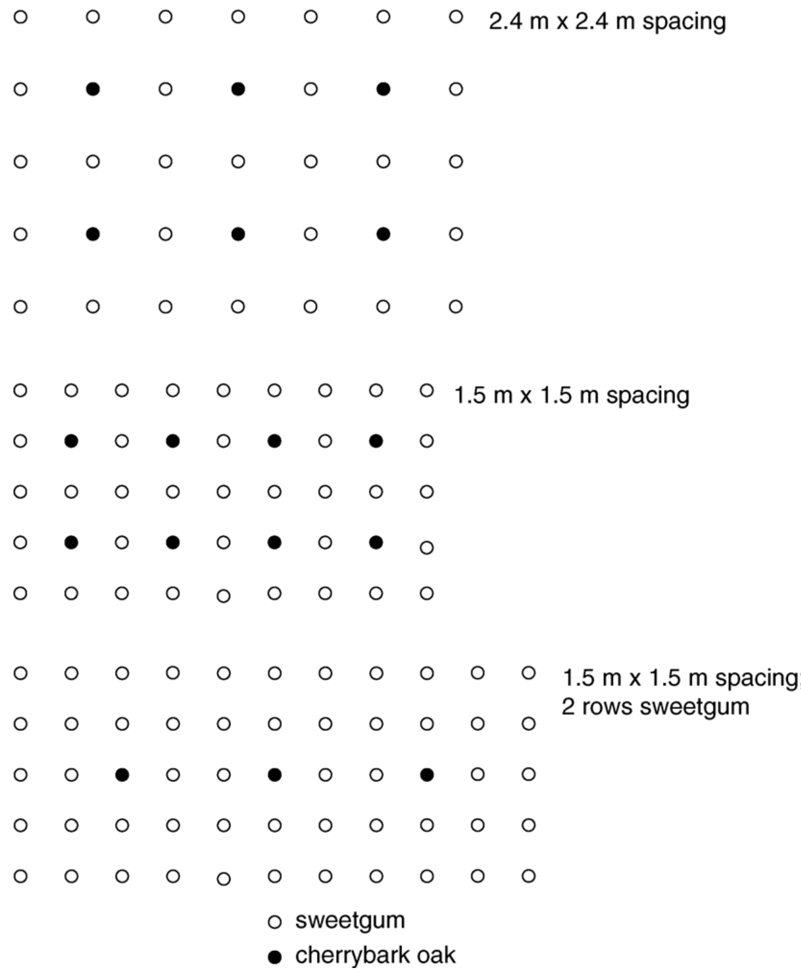

Fig. 2. Spacing arrangement of cherrybark oak and sweetgum seedlings in three spacing arrangements.

(5 ft × 5 ft; designated as 1.5 m) spacing using the same row design as the 2.4 m spacing described above (Fig. 2). The closer spacing was chosen based on previous work in natural stands of cherrybark oak and sweetgum (Clatterbuck, 1985). A total of 45 cherrybark oak seedlings and 168 sweetgum seedlings were planted in 11 rows (5 rows alternating cherrybark oak and sweetgum seedlings). This spacing arrangement is equivalent to 909 cherrybark oak seedlings ha^{-1} and 3395 sweetgum seedlings ha^{-1}.

The third spacing arrangement involved planting mixtures of cherrybark oak and sweetgum on a 1.5 m × 1.5 m spacing similar to the 1.5 m arrangement except two rows of sweetgum were planted on each side of the alternating cherrybark oak and sweetgum row for a total of 14 sweetgum seedlings surrounding each cherrybark oak seedling (designated as 1.5 mD with the "D" representing "double" or two pure rows of sweetgum; Fig. 2). This arrangement was used to provide greater inter-specific competition in case the first row of sweetgum was quickly overtopped. A total of 27 cherrybark oak and 182 sweetgum seedlings were planted in 11 rows (3 rows alternating cherrybark oak and sweetgum seedlings). This spacing arrangement is equivalent to 556 cherrybark oak seedlings ha^{-1} 1 and 3749 sweetgum ha^{-1}.

The site was disced prior to planting. Seedlings were then planted in March 1982. Cherrybark oak seedlings were 2-0 stock produced in a nursery at the Blackjack Research Facility on the Mississippi State University campus (about 24 km from the study site). Sweetgum seedlings were 1-0 stock purchased from a private nursery. Thirty-six cherrybark oak seedlings (34% of the total number of cherrybark oak planting spots) were replanted with 1-0 stock following first-year mortality with the 2-0 stock. Periodic mowing was conducted within and between rows during the first two growing seasons following planting.

2.3. Measurements

Height and diameter measurements were conducted following the 1989, 1991, 1998, and 2002 growing seasons (stand ages 8, 10, 17, and 21, respectively). Tree height was measured with a height pole in 1989 and 1991, and with a laser height instrument in 1998 and 2002. Diameter (dbh, 1.37 m above ground) was measured with a standard diameter tape. In 2002, crown classes (dominant, codominant, intermediate, and overtopped; Smith, 1986) were assigned for each tree based on the tree crown's position and condition (Meadows et al., 2001).

2.4. Analyses

Statistical analyses were conducted using PC-SAS (SAS, 1986). Each cherrybark oak and surrounding sweetgum were considered individual experimental units. Survival was calculated as the number of trees alive at each measurement time, including replanted cherrybark oak seedlings. Sweetgum height and dbh within each cherrybark oak plot were averaged and compared with cherrybark oak using repeated-measures analysis. The Wilks' Lambda test was used to test the effect of time and time by species interactions. Only those plots with a live cherrybark oak following the 2002 measurements were included in all analyses. An alpha level of 0.05 was used to determine statistical significance.

3. Results

3.1. Survival

Survival across all spacings was 82 and 99% for cherrybark oak and sweetgum, respectively. Cherrybark oak survival following the 2002 growing season ranged from 89% at the 2.4 m spacing to 78% at the 1.5 mD spacing, while sweetgum survival was nearly 100% across all spacings (Table 1). Much of the cherrybark oak mortality occurred prior to the 1989 measurements, while only one sweetgum tree died since 1989.

3.2. Height

Differences of 1.3–3.0 m in height occurred between cherrybark oak and sweetgum trees by 2002 (Fig. 3). Time and time by species interactions were different across all spacings ($p \leq 0.0012$ for each analysis within each spacing) indicating that while both species grew in height over time, their patterns of height growth differed. During the first measurement (1989) sweetgum trees were taller than cherrybark oak across each of the three spacings ($p = 0.0002$, 0.0126, and 0.0094 for the 2.4 m, 1.5 m, and 1.5 mD, respectively). Two years later, sweetgum was still taller than cherrybark oak in the 2.4 m ($p = 0.0009$) and 1.5 mD ($p = 0.0395$) spacings, but no difference existed in the 1.5 m spacing ($p = 0.1933$). Seventeen years after planting (1998), no height differences existed in the 2.4 m ($p = 0.1061$) and 1.5 mD ($p = 0.2053$) spacings, while cherrybark oak was 1.9 m taller than sweetgum in the 1.5 m spacing ($p = 0.0001$). By 2002, cherrybark oak was taller than sweetgum across all spacing ($p = 0.0221$, 0.0001, and 0.0287 for the 2.4 m, 1.5 m, and 1.5 mD, respectively).

Table 1
Survival (%) of cherrybark oak and sweetgum planted in mixture at three spacing arrangements in Oktibbeha County, Mississippi, USA

Spacing	Species	n	1989	1991	1998	2002
2.4 m	Cherrybark oak	35	89	89	89	89
	Sweetgum	138	100	100	100	100
1.5 m	Cherrybark oak	45	82	82	82	80
	Sweetgum	168	100	100	100	99
1.5 mD	Cherrybark oak	27	78	78	78	78
	Sweetgum	182	99	99	99	99

3.3. dbh

Cherrybark oak and sweetgum dbh development patterns were similar to their respective height development patterns (Table 2). At the time of the 1989 and 1991 measurements, sweetgum was larger in dbh compared to cherrybark oak in the 2.4 m and 1.5 mD spacings. The dbh by age 17 years (1998) at these two spacings was similar between the two species and by 2002 cherrybark oak dbh was larger than sweetgum (Table 2). Cherrybark oak and sweetgum dbh were similar during the 1989 and 1991 measurements in the 1.5 m spacing. Afterward, cherrybark oak dbh was greater than sweetgum (Table 2).

3.4. Crown classes

A majority of the cherrybark oak crowns were in the dominant or codominant position at the time of the 2002 measurements (Table 3). No sweetgum crowns were classed as dominant and <3% were considered codominant. A majority of the sweetgum crowns were overtopped in the 1.5 m and 1.5 mD spacings, while 97% of the sweetgum crowns in the 2.4 m spacing were intermediate or overtopped.

4. Discussion

4.1. Stand development

The ascendance of cherrybark oak above sweetgum by age 21 years followed natural stand development patterns of cherrybark oak–sweetgum stratification. Planted sweetgum dominated cherrybark oak during the early years of stand development in each of the three spacing arrangements (Fig. 3). Sweetgum is noted for invading recently-disturbed areas and old fields and developing into "sweetgum thickets" (Kormanik, 1990). Less obvious is the concurrent establishment of red oak species, whose stem density is dwarfed by the more numerous sweetgum. But

Table 2
Diameter (dbh, 1.37 m) in cm of cherrybark oak and sweetgum planted in mixtures at 3 spacing arrangements in Oktibbeha County, Mississippi, USA

Spacing	Species	1989	1991	1998	2002
2.4 m	Cherrybark oak	4.6 (2.0)	7.1 (2.5)	14.0 (4.6)	17.8 (5.8)
	Sweetgum	6.1 (0.8)	8.6 (0.8)	13.0 (1.0)	14.2 (1.3)
p-Value		0.0008	0.0009	0.2892	0.0015
1.5 m	Cherrybark oak	3.3 (1.5)	4.8 (2.3)	9.7 (4.8)	12.4 (6.6)
	Sweetgum	3.6 (0.5)	5.1 (0.8)	7.4 (0.8)	7.6 (0.8)
p-Value		0.2364	0.5936	0.0001	0.0001
1.5 mD	Cherrybark oak	2.5 (1.3)	4.1 (1.5)	8.6 (4.3)	11.4 (6.4)
	Sweetgum	3.3 (0.8)	5.1 (0.8)	7.9 (0.5)	8.4 (0.5)
p-Value		0.0122	0.0275	0.0969	0.0025

Values in parentheses represent ±1 standard error.

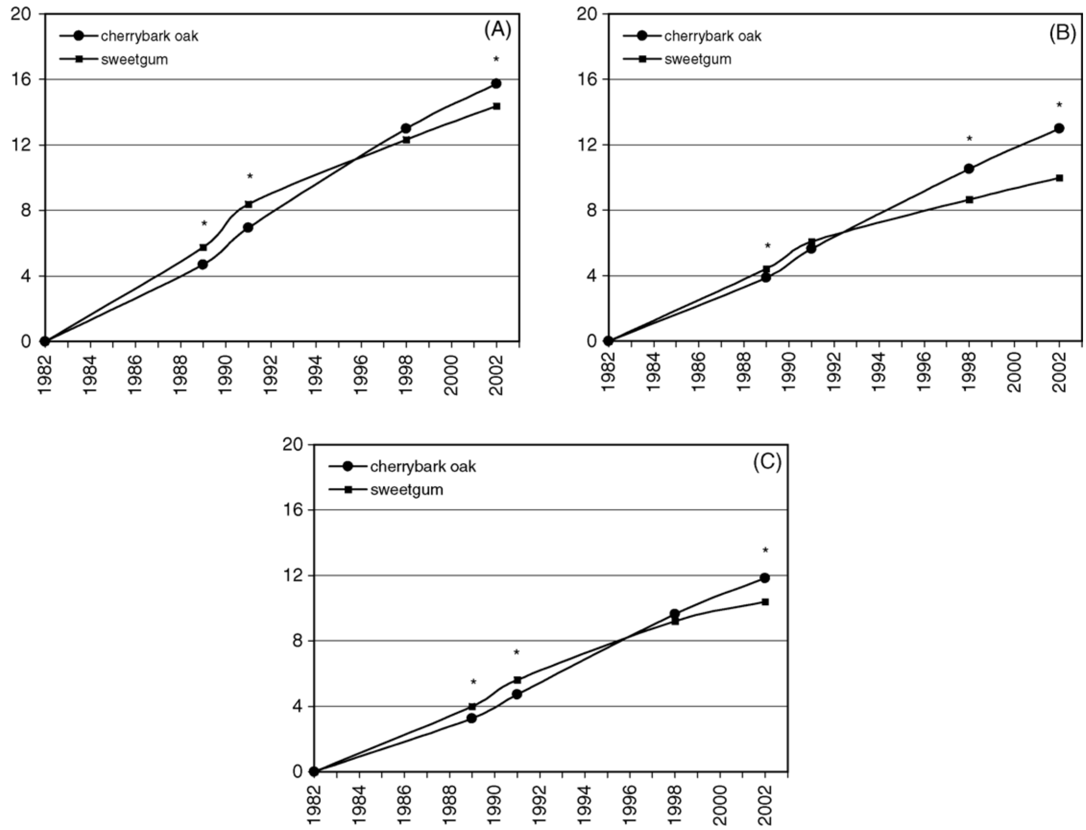

Fig. 3. Height development of cherrybark oak and sweetgum planted in mixtures at three spacing arrangements in Oktibbeha County, Mississippi, USA: (A) 2.4 m × 2.4 m spacing; (B) 1.5 m × 1.5 m spacing; (C) 1.5 m × 1.5 m spacing with two rows of sweetgum. Asterisks indicate statistical significance at $p \leq 0.05$.

sweetgum height development slows during the stem exclusion stage of stand development, thereby letting other species better compete and eventually overtop sweetgum. By age 17 years, cherrybark oak had either caught up to or passed sweetgum in height and diameter, depending on spacing arrangement, and was significantly taller in height and larger in diameter by age 21 years. A similar pattern of oak stratification has been documented in cherrybark oak–sweetgum mixtures in natural stands (Clatterbuck et al., 1985; Clatterbuck and Hodges, 1988), bottomland red oak [cherrybark oak, water oak (*Q. nigra* L.), and willow oak (*Q. phellos* L.)]–sweetgum–American ironwood (*Carpinus carolinana* Walt.) mixtures in Arkansas and Mississippi (Bowling and Kellison, 1983; Johnson and Krinard, 1988), and northern red oak (*Q. rubra* L.)–red maple (*Acer rubra* L.)–black birch (*Betula lenta* L.) mixtures in the northeastern United States (Oliver, 1978).

Table 3
Percent of trees by crown class following the 2002 growing season for cherrybark oak and sweetgum planted in mixture at 3 spacing arrangements in Oktibbeha County, Mississippi, USA

Spacing	Species	Dominant	Codominant	Intermediate	Overtopped
2.4 m	Cherrybark oak	19.4	54.8	19.4	16.5
	Sweetgum	0.0	2.9	65.9	31.2
1.5 m	Cherrybark oak	19.4	33.3	16.7	30.6
	Sweetgum	0.0	1.8	19.8	78.4
1.5 mD	Cherrybark oak	38.1	23.8	19.0	19.0
	Sweetgum	0.0	2.2	41.1	56.7

Clatterbuck and Hodges (1988) found that the spacing of sweetgum trees had a profound effect on the development of individual cherrybark oak trees. When sweetgum trees averaged 1.8–5.5 m from a cherrybark oak tree then the cherrybark oak exhibited a restricted pattern of development. The cherrybark oak would, early in life, have a lower height and dbh than neighboring sweetgum. But as long as the cherrybark oak was not overtopped, i.e., it was receiving some direct overhead sunlight (Fig. 4), then cherrybark oak would eventually catch and then stratify above sweetgum by age 23–25 years (Clatterbuck and Hodges, 1988). Clatterbuck (1985) and Lockhart et al. (2005) suggested several reasons for this pattern of cherrybark oak–sweetgum stratification in natural and artificial stands:

(1) *Crown architecture*: sweetgum exhibits an excurrent crown form in which branches remain relatively close to the main bole, even when grown in an open environment. Cherrybark oak exhibits a deliquescent crown form when grown in the open, producing a large crown on a relatively short bole. When competing with other trees, cherrybark oak exhibits a semi-excurrent crown form because of competition with neighboring trees but shifts to a decurrent, spreading crown form on a taller bole after emergence into the overstory above species such as sweetgum.

Fig. 4. Mixed cherrybark oak–sweetgum plantation at age 10 years. Arrow points to a cherrybark oak sapling. Note the open canopy over the cherrybark oak sapling despite being surrounded by eight taller sweetgum saplings.

(2) *Crown abrasion*: sweetgum twigs are smaller and more brittle at a given age compared to cherrybark oak twigs; therefore, during wind events (especially squall lines associated with severe thunderstorms), the terminal buds and twigs of sweetgum tend to break when scraped against twigs of neighboring cherrybark oak trees.
(3) *High initial sweetgum density*: a high initial sweetgum density may delay intra-specific crown differentiation leading to sweetgum stagnation (Johnson, 1968). Cherrybark oak could then ascend above sweetgum because of little or no sweetgum height growth.
(4) *Phenology*: bud break in cherrybark oak, though occurring several days later than in adjacent sweetgum, occurs basipetally (from the top of the crown towards the bottom), while bud break in sweetgum occurs acropetally (begins at the base of the crown and proceeds to the top) (Young, 1980). Earlier budbreak and early height growth by cherrybark oak in the upper part of its crown may give it a competitive advantage over adjacent sweetgum of similar height.

Of particular importance may be the crown abrasion aspects of inter-specific competition. In the study plantation where cherrybark oak trees were similar in height or taller than neighboring sweetgum, the sweetgum branches were broken, especially in the terminal part of the crown. Subsequent sweetgum crown development was from lateral branches opposite the cherrybark oak, i.e., the sweetgum crown tended to "grow away" from the cherrybark oak crown as the cherrybark oak crown expanded outward. Further crown development resulted in a cherrybark oak crown dominating over suppressed sweetgum crowns (Table 3). At this point, crown competition shifted from inter-specific competition between cherrybark oak and adjacent sweetgum to intra-specific competition among stratified cherrybark oaks. This shift in competition follows stand development patterns found in black birch–red maple–northern red oak mixtures (Kittredge, 1988).

The ascendance of cherrybark oak above sweetgum even occurred on the 1.5 m spacing. Clatterbuck (1985) indicated that cherrybark oak usually followed an overtopped development pattern when the spacing with adjacent sweetgum averaged 1.8 m or less. The 1.5 m and 1.5 mD spacing arrangements in this study resulted in 8 or 14 sweetgum seedlings surrounding each cherrybark oak seedling. The closest sweetgum seedling was 1.5 m away from each cherrybark oak seedling. In natural mixed-species stand development, the average spacing of 1.8 m that resulted in sweetgum overtopping cherrybark oak undoubtedly included sweetgum seedlings considerably closer to cherrybark oak than 1.5 m. The rapid early height growth of sweetgum, especially sweetgum sprouts, combined with the relatively slow early height growth patterns of cherrybark oak, would give sweetgum a competitive advantage at these closer spacings. In the plantation setting, 1.5 m is apparently enough distance to keep individual sweetgum seedlings from overtopping a majority of the cherrybark oak seedlings. Cherrybark oak seedlings were able to become well established and then proceeded with rapid height growth to stratify above sweetgum.

4.2. Stem reconstruction comparison

The present study represents one of the first studies to test a reconstruction study by duplicating results from natural, mixed-species stands in artificial species mixtures. Stand reconstruction incorporates stem analysis techniques to determine a tree's height and age history. These techniques have long been used as one way to develop site index graphs and equations (e.g., Curtis, 1964; Newberry, 1991; Splechtna, 2001). More recently, stem analysis has been used to reconstruction the development of individual stands (Henry and Swan, 1974; Oliver and Stephens, 1977; Oliver, 1978; O'Hara, 1986; Clatterbuck and Hodges, 1988; Tift and Fayvan, 1999). Comparison of the height development patterns of individual species within stands has had a profound impact in the silviculture of mixed-species stands. Long-held beliefs about stand development pathways, i.e., relay versus initial floristics (Clements, 1916; Egler, 1954, see Oliver and Stephens, 1977 for a review of autogenic and allogenic succession), a reverse-J diameter distribution is automatically an uneven-aged stand (Ashton and Peters, 1999; Oliver and Larson, 1996), etc., have changed as a result of the studies cited above among others.

The stratification of red oak, in this case cherrybark oak, above sweetgum in an artificial setting confirms results found by Clatterbuck et al. (1985) and Clatterbuck and Hodges (1988). The ascendence of cherrybark oak above sweetgum in a plantation setting occurred between stand age 17 and 21 years across all three spacing arrangements. Clatterbuck and Hodges (1988) found stratification of cherrybark oak above sweetgum occurred around age 21–23 years in old-field stands, while Johnson and Krinard (1988) found stratification of bottomland red oaks above sweetgum occurred around age 27–30 years following clearcutting. The earlier stratification of cherrybark oak above sweetgum in an artificial setting may reflect a lower initial stem density and lower species diversity compared to the natural stands in Clatterbuck and Hodges (1988) and Johnson and Krinard (1988), although site conditions and type of disturbance may have also influence the timing of stratification. Results from the present study indicate that stand development of natural, mixed-species stands can be duplicated in artificial mixtures. This finding has important implications for ongoing afforestation efforts in the LMAV as described below.

4.3. Mixed-species plantations in the LMAV

Deforestation of the LMAV for agriculture production represents an example of acute degradation. Ashton et al. (2001) described acute degradation as a one-time disturbance that dramatically alters forest composition, structure, and function. Conversion of forests to agriculture production also results in accelerated rates of soil erosion, loss of nutrients – especially nitrogen – and reduced soil organic matter content, in addition to the loss of many forest regeneration mechanisms. Allen (1990, 1997) and McCoy et al. (2002) showed that natural regeneration of abandoned agricultural fields is limited to about 100 m from the edge of adjacent forests. Natural regeneration of abandoned agricultural fields is especially problematic in the LMAV because of the large size of fields (often >400 ha), which limits wind and animal seed dispersal. Furthermore, the presence of levees along rivers and major streams limits flooding as an agent of seed dispersal. Stanturf et al. (2001) estimated that it would take about 80 years for a typical abandoned agricultural field in the LMAV to naturally regenerate sufficiently for the developing forest to achieve canopy closure. Therefore, simply abandoning these former agricultural fields is not an acceptable option to regenerate these areas to forests.

A typical afforestation objective in the LMAV involves planting 746 oak seedlings ha^{-1} on a 3.7 m × 3.7 m spacing (Schweitzer and Stanturf, 1997). Poor seedling survival following planting has been common in the LMAV (Schweitzer, 1998). In cases where survival has been acceptable, the development of pure oak plantations has resulted in less-than-ideal wildlife habitat following canopy closure (Twedt and Portwood, 1997). Development of pure oak plantations also may result in the development of poor quality oak sawtimber trees because of the early onset of intra-specific competition (Wormald, 1992; Ashton et al., 1993). Oak trees are sensitive to stress (Johnson et al., 2002). One form of stress for oak trees is early intra-specific competition where oak trees are under intense competition following canopy closure. It has been our observation that few oaks stratify above neighboring oaks in the upper canopy, resulting in oak trees with low live crown ratios, low diameter growth rates, and eventual development of epicormic branches along the main bole. Later thinning operations may exacerbate the epicormic branching problem as boles of stressed oak trees are exposed to sunlight (Meadows, 1996). Costly precommercial thinning may be necessary to avoid these problems associated with early onset of intra-specific oak competition so desired oak trees can maintain or increase their vigor (Johnson et al., 2002).

Planting intimate tree species mixtures has many benefits in afforesting floodplain sites. Planting fewer oaks, but more seedlings of other species, may result in greater oak seedling survival and better quality oak trees. Initiating inter-specific competition early in the development of a plantation, as opposed to intra-specific competition found in pure oak plantations, may reduce the stress on individual oak trees and reduce or eliminate the need for precommercial thinning operations. Other benefits include increased merchantable bole lengths and greater vertical structural diversity associated with canopy stratification among species. Commercial thinning operations can utilize the trainer species, i.e., species that help the development of desired species, after they have served their purpose in the development of oak crop trees. These species, e.g., sweetgum, can also serve as points for skidders to turn with their load of logs reducing damage to the lower bole of crop trees (Meadows, 1995).

Results from this study indicate that cherrybark oak, planted in intimate mixtures with sweetgum, develop similarly to bottomland red oak–sweetgum mixtures in natural stands (Johnson and Krinard, 1976, 1983, 1988; Bowling and Kellison, 1983; Clatterbuck and Hodges, 1988). Best individual cherrybark oak development occurred at the 2.4 m × 2.4 m spacing arrangement. These trees were taller in height and larger in diameter compared to cherrybark oaks in the 1.5 m and 1.5 mD spacing arrangements (Table 2; Fig. 3). Sweetgum in the 2.4 m spacing arrangement did reach a pulpwood merchantability standard (10 cm) before being overtopped by cherrybark oak. Therefore, we recommend that planting intimate mixtures of cherrybark oak and sweetgum be conducted on 2.4 m × 2.4 m spacings. A 3.0 m × 3.0 m plantation spacing (10 ft × 10 ft) would probably be acceptable, but the current standard of 3.7 m × 3.7 m spacing arrangement is probably too wide for sweetgum to have much influence on the early development of cherrybark oak.

The present cherrybark oak–sweetgum mixture was planted on a minor terrace about 150 km from the LMAV. Soil and subsurface water flow conditions are not similar to the LMAV. Furthermore, cherrybark oak is not a major species in the LMAV, while sweetgum is a major species. Major red oak species in the LMAV include water oak, willow oak, and Nuttall oak (*Q. nuttallii* Palmer). Given these differences, stand development patterns may be similar when these red oak species are planted with other potential trainer species common to the LMAV including boxelder (*A. negundo* L.), sugarberry (*Celtis laevigata* Willd.), and green ash. The key in developing intimate bottomland hardwood plantation mixtures in the LMAV is to set specific management objectives including ensuring species compatibility (Menalled et al., 1998; Stanley and Montagnini, 1999), matching species to the site conditions (including soils and drainage conditions), and providing thorough oversight of the planting operation (Gardiner et al., 2002).

One objective in planting intimate mixtures of oak with other species is to focus management decisions on the individual oak tree. Quality stand management in bottomland hardwood forests requires that management decisions be made based on the characteristics of individual crop trees rather than following pre-designed trees ha^{-1}, basal area, stocking, or volume requirements (Meadows and Skojac, in preparation). The focus of quality stand management has been in natural stands, but as the thousands of hectares of oak plantations in the LMAV and other floodplain sites across the southeastern United States mature, decisions will be needed on how to manage these stands in the future. Planting intimate mixtures of oaks with other species can provide a greater variety of options. Quality stand management principles can best be integrated in afforestation projects when an understanding of stand development patterns among the species in the mixture is understood or information from natural stand counterparts can be utilized.

Acknowledgements

We thank the U.S. Fish and Wildlife Service Noxubee National Wildlife Refuge for permission to conduct this study on refuge property. E. Gardiner, J. Groninger, S. Meadows, J. Wessman, and two anonymous reviewers provided constructive comments on earlier versions of this manuscript.

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