A Stand-Development Approach to Oak Afforestation in the Lower Mississippi Alluvial Valley

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ABSTRACT

Oak (*Quercus* spp.) afforestation in the Lower Mississippi Alluvial Valley has involved planting 1-year-old bareroot seedlings on a relatively wide spacing in single-species stands or planting light-seeded species with oaks to form mixed-species stands. In the former case, the developing single-species stands have limited future management options because they do not provide structures that favor quality wildlife habitat or quality sawtimber production. In the latter case, species mixtures are being planted with little knowledge of subsequent stand development, leading to an inability to predict future stand composition for management purposes. In this article, we present a system to determine bottomland tree planting mixtures that will create single-cohort, mixed-species stands with a component of high-quality bottomland oak. Using individual species ecological life-history characteristics, such as early height growth pattern, relative twig diameter and durability, and developmental patterns in natural stands, bottomland species are rated for their ability to provide beneficial training effects that will lead to the development of quality oak boles. Incorporating such a system to determine species value in mixtures should provide an increased number of future options to meet explicit management objectives and promote improved restoration of bottomland hardwood ecosystems.

Keywords: interspecific competition, intraspecific competition, mixed-species plantations

Oaks (*Quercus* spp.) represent one of the most widely distributed genera of tree species throughout the world. Approximately 600 species of oak exist, occurring from temperate regions to Mediterranean and tropical regions (Stein et al. 2003, Kappelle 2006). Oak-dominated ecosystems provide many important functions including carbon fixation and storage, biogeochemical cycling and storage, and mast and shelter for a wide variety of wildlife species (Miller and Lamb 1985, Johnson et al. 2002). Oak-dominated ecosystems also provide many values to humans, including food, shelter, medications, recreation, and various wood products including veneer, lumber, and pulp (Miller and Lamb 1985, Johnson et al. 2002, Stein et al. 2003). Individual oak trees have even attained fame for historical events that occurred under their crowns (Vickery 2004, Jablonski 2005). The many books and symposium proceedings involving oak history, ecology, silviculture, and management establish the importance of oaks to society (e.g., White and Roach 1971, Laursen and DeBoe 1991, Loftis and McGee 1993, Dreyer and Aussenac 1996, Johnson et al. 2002, Kappelle 2006, Logan 2006).

In the United States, oaks are considered the most important assemblage of hardwood species (Harlow et al. 1996). About 70 species occur in the United States, with over 40 species and varieties occurring east of the 100th meridian (Little 1979). Stein et al. (2003) indicated that oak-dominated ecosystems comprise 68% of hardwood forests, or about 192 million ac. Oaks are the primary genera in the Eastern Deciduous Forest, which was formerly called the *Quercus–Fagus* Formation (Clements 1916, 1928; Weaver and Clements 1938 from Braun 1950). Although oaks are the primary species in many forest cover types (Society of American Foresters [SAF] 1980), and a significant amount of research has focused on problems with natural and artificial regeneration of these species (Johnson 1979, Crow 1988, Loftis and McGee 1993), ecologically based approaches to establishing mixed-species bottomland oak stands do not exist. In this article, we describe (1) the use of bottomland oaks in afforestation practices, especially in the Lower Mississippi Alluvial Valley (LMAV), (2) difficulties associated with current bottomland afforestation practices, (3) a system that identifies bottomland species compatible in single-cohort mixtures with oak species, and (4) specific mixtures of bottomland oak and other species to address afforestation difficulties.

Background

LMAV

The LMAV is in the Subtropic Division of the Humid Temperate Domain (Bailey 1995). It extends 600 mi and covers 24 million ac in 7 states in the south central United States, ranging from southern Illinois to southern Louisiana. About 85% of this land is situated in the tri-state area of Arkansas, Mississippi, and Louisiana (Gardiner and Oliver 2005). A majority of the LMAV is in private ownership, with the remainder in public and nonprofit entities (Wear and Greis 2002). Gardiner and Oliver (2005) provide an overview of the climate and soils found in the region.

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Land-Use Patterns

Before European settlement, forests covered much of the LMAV (National Research Council [NRC] 1992, Hefner and Brown 1985) although the exact extent of forests during this time is unknown because of the indeterminate role of American Indians and their clearing practices on the forest resource (Buckner 1989, Hamel and Buckner 1998, Fickle 2001). After settlement, documented forest clearing for agriculture began (Barry 1997). Deforestation reached a maximum of 300,000 ac yr^{-1} during the 1950s through the 1970s in response to high soybean (*Glycine max* [L.] Merr.) prices (Spencer 1981) and a prolonged drought that gave a false sense of security in farming floodplain soils that have a high clay content and are normally wet much of the year (Stanturf et al. 2001). By the early 1990s only about 5 million ac of forests remained in the LMAV (The Nature Conservancy 1992). Furthermore, all of the land in the LMAV has been subject to altered surface and subsurface water flow patterns caused by stream channelization and rerouting and the construction of levees, ditches, roads, and dams. Notable among these is the mainline levee system along the Mississippi River that has reduced much overland and backwater flooding (Barry 1997). The extensive land clearing for row-crop agriculture and urban development combined with changes in surface and subsurface water flow patterns has led to the declaration that the LMAV is one of the most endangered ecosystems in the United States (Noss et al. 1995).

Afforestation in the LMAV—Single-Cohort, Single-Species Stands

During the 1980s, concern was expressed over the loss of bottomland forest ecosystems in the LMAV (Haynes et al. 1993). Efforts began to restore these bottomland ecosystems through a variety of treeplanting projects (Allen and Kennedy 1989, Allen 1990, Haynes et al. 1993). With the advent of federal and state government programs to aid in costs of planting trees, especially the Conservation Reserve Program and the Wetland Reserve Program (Kennedy 1990, Haines 1995, Stanturf et al. 1998), about 500,000 ac of former agricultural land have been planted with bottomland hardwood species by 2001 (Gardiner and Oliver 2005). Although afforesting former agricultural fields is not considered complete bottomland forest ecosystem restoration, it is an important first step (Stanturf et al. 2000, 2001).

Afforestation in the LMAV has involved planting hard mast species, primarily 1-year-old bareroot oak (*Quercus* spp.) and sweet pecan (*Carya illinoinensis* [Wang] K. Koch) seedlings, on a 12 × 12-ft spacing, in either single-species stands or mixtures of oak species or oak species and sweet pecan (Stanturf et al. 2000, Schoenholtz et al. 2001). These species were favored in planting on former agricultural fields for their function in wildlife habitat and because seed dispersal into such areas is limited. Native, 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.), were assumed to naturally colonize old fields as their seeds are dispersed by floodwater (Stanturf et al. 1998, 2000). Stanturf et al. (2000) summarized problems with this traditional approach to afforestation in the LMAV: (1) light-seeded species reliably established only within about 300 ft of forest edges (Allen 1990, 1997; McCoy et al. 2002); (2) homogeneous oak plantations do not provide early complex stand structure that is valued for wildlife habitat (King and Keeland 1999, Twedt et al. 1999); (3) stocking densities typically achieved under federal cost-share programs usually limit timber management options, thereby restricting potential management objectives; and (4) carbon sequestration may be lower in oak monocultures than in mixed-species stands.

Figure 1. Twenty-year-old water oak plantation in Sharkey County, Mississippi, showing little canopy stratification and poor self-pruning of individual trees. (Photo by Brian Roy Lockhart.)

Oak plantations, either single species or a mixture of oak species, typically do not develop satisfactory stem quality (Figure 1). Wide spacing on many afforested sites allows oak stems to develop large branches on the lower bole before the onset of crown closure (Oliver and O'Hara 2005). These branches slowly die after crown closure but persist on the bole for many years. Concurrently, slow diameter growth occurs from intraspecific competition between the oak trees. The slow shedding of large dead limbs and slow diameter growth results in large surface knots, which degrade the lower bole, significantly lowering stem quality and value (Kenna 1981, 1994). Furthermore, intense intraspecific oak competition places the stand under stress promoting epicormic branches along the bole. These branches further reduce stem value (Meadows and Burkhardt 2001). Precommercial thinning can alleviate this stress (Oliver and O'Hara 2005), but it is often not practiced because of the costs burdened by the landowner.

More recently, managers have established species mixtures with oaks and native light-seeded species (Jon Wessman, pers. comm., US Fish and Wildlife Service, July 11, 2006). These mixtures were established to increase tree species diversity, which is assumed to result in improved wildlife habitat. Although the trend toward establishing species mixtures is warranted, most mixtures are assigned with little concern for species compatibility.

Stand Development Approach—Single-Cohort, Mixed-Species Stands

Overview

Problems inherent to single-species oak stands can be overcome by planting species mixtures that encourage interspecific competition instead of intraspecific oak competition early in stand development. Mixed-species forest plantations are typically plantings of two or more tree species wherein each species has a specific role in the mixture. Unlike single-species plantations, mixed-species plantations require knowledge of each species silvical characteristics and the interaction of these characteristics between species and site conditions (Larson 1992, Oliver 1992). Failure to consider individual species requirements and the effects of the mixture on requirements can lead to plantation failure.

Advantages and Disadvantages

The benefits of mixed-species plantations are many compared with single-species plantations (Kelty 2006, Nichols et al. 2006). Some mixed-species plantation mixtures can provide greater yields than single-species plantations (Binkley and Greene 1983, Binkley 1984, Schlesinger and Williams 1984, DeBell et al. 1985, Mielikainen 1985, Kelty 1986, Tham 1988, DeBell et al. 1989, Paschke et al. 1989, Groninger et al. 1997, Nichols et al. 2001). Greater structural diversity of habitat conditions in mixed-species plantations provides for improved wildlife habitat compared with single-species plantations (Twedt and Portwood 1997, Twedt and Wilson 2002). Mixed-species plantations may also increase carbon sequestration (Montagnini and Porras 1998, Kaye et al. 2000) and enhance recruitment of natural regeneration compared with single-species plantations (Parrotta 1999, Carnevale and Montagnini 2002, Twedt 2006). Finally, mixed-species plantations may reduce the risk of plantation failure compared with single-species plantations by providing greater resistance to damaging agents such as insects, pathogens, and wind (Watt 1992, Montagnini et al. 1995, Nichols et al. 1999).

A disadvantage to mixed-species plantations is their high establishment and maintenance costs (Montagnini et al. 1995, Gardiner et al. 2002) when control of competing herbaceous plants is required for successful establishment (Bowersox and McCormick 1987; Ponder 1987; von Althen 1991; Ezell 1995, 1999; Groninger et al. 1997; Ezell and Catchot 1998; Ezell et al. 1999). On former agricultural fields in the LMAV, woody vines are particularly difficult to control (Stanturf et al. 2004). In addition, care must be taken to match species with site requirements (Putnam et al. 1960, Hodges 1997) and ensure compatibility of development patterns of selected species (Bhatnagar et al. 1993). Mixed-species plantations may also reduce harvesting efficiency compared with single-species plantations because harvesting equipment must navigate around selected species.

Key Considerations for Constructing Single-Cohort, Mixed-Species Stands

Ashton et al. (2001), who worked on restoration of tropical ecosystems, forwarded several principles that should be considered when designing mixed-species forest plantations. Many of these principles, which account for ecological relationships between individual species and site conditions, can be applied to mixed-species stands in the LMAV. An inherent assumption made by Ashton et al. (2001) is that mixing shade-intolerant species with shade-tolerant species or pioneer species with later-successional species is preferable to planting species of similar shade tolerances or successional status. Stands planted with species of similar shade tolerances or successional status develop similar to single-species stands (Guldin and Lorimer 1985) with few of the benefits associated with mixtures of contrasting species.

When species selected for planting in mixtures are successionally compatible (i.e., shade-tolerant species with shade-intolerant species or pioneer species with later-successional species), early successional species will enhance site conditions for subsequent development of later-successional species, similar to pathways found in autogenic succession (Hodges 1997). These mixtures also facilitate the development of stratified canopies that increase the number of niches for wildlife while concurrently providing interspecific competitive conditions that enhance the development of quality boles on desired later-successional species. Thus, a primary consideration is that the successional pathways of species or species guilds must be known before planting.

Additionally, the spatial arrangement of the mixture should be consistent with differential self-thinning among species (i.e., more shade-intolerant species surrounding shade-tolerant species or more pioneers surrounding later-successional species) and the intra- and interspecific spacing among trees should be compatible with their known crown morphologies (Ashton et al. 2001). Early successional species tend to be shade-intolerant species; therefore, their crown morphologies exhibit strong epinastic control with relatively small compact crowns. When grown in natural stands, these species readily self-thin among themselves (e.g., black willow [*Salix nigra* Marsh.], eastern cottonwood [*Populus deltoides* Bartr. ex Marsh.], and sweetgum). Plantation spacings must be wide enough to reduce the self-thinning aspect of these species and allow for the development of later-successional species. Ideally, later-successional species will eventually stratify above the early successional species. Later-successional species (e.g., oaks in bottomland ecosystems), often exhibit an excurrent tree form when grown in competition with other trees but change to a decurrent, spreading form when they stratify above other species (Oliver and Larson 1996).

Finally, Ashton et al. (2001) recommended that shade-tolerant late-successional canopy tree species be carefully selected to insure compatibility with the site. In southern US bottomland ecosystems, we recommend all species be compatible with sites regardless of their successional status. Floodplain soils vary greatly in their pH, texture, and drainage classes, resulting in a variety of species-site relationships (Stanturf and Schoenholtz 1997). Understanding these relationships among species is essential to developing planting prescriptions for mixed-species plantations in the LMAV.

A System for Mixed-Species Bottomland Oak Stands

Forest restoration in the LMAV should be designed around ecological relationships in bottomland ecosystems. Knowledge of species autecology, species-site relationships, and successional pathways as they impact stand development patterns are necessary to develop successful mixed-species planting prescriptions. Unfortunately, no know mixed-species plantations exist in the LMAV that take into consideration development patterns in natural stands. The system described later applies knowledge of species development patterns in mixed-species natural stands to potential artificial mixtures. Based on stand development work in bottomland hardwood ecosystems (Bowling and Kellison 1983, Clatterbuck and Hodges 1988, Johnson and Krinard 1988, Oliver et al. 2005), we have identified several silvical characteristics that are used as drivers in this system.

Tables 1 and 2 list oak and nonoak species, respectively, that are commonly found in LMAV forest overstories, along with silvical information. Flood tolerance refers to the inherent tolerance of the species to the stressful conditions created by frequency and duration of flooding (McKnight et al. 1981). Shade tolerance refers to the capacity of a species to compete for survival under shaded conditions; likewise, shade intolerance refers to the capacity of a species to compete for survival under direct sunlight conditions (Helms 1998). These criteria are also important for matching species to site conditions. Furthermore, knowledge of shade tolerances is needed

Table 1. Oak species found in the Lower Mississippi Alluvial Valley (LMAV) along with their respective silvical characteristics.

Species	Occurrence in the LMAV[a]	Flood tolerance	Shade tolerance
Quercus alba (white oak)	Widely on well-drained oldest alluvium and terraces	Intolerant	Moderately intolerant
Quercus bicolor (swamp white oak)	Scattered on poorly drained, heavy soils; edge of swamps	Moderately tolerant	Intermediate[b]
Q. lyrata (overcup oak)	Widely on poorly drained, heavy soils; scattered on better sites	Moderately tolerant	Moderately intolerant
Q. michauxii (swamp chestnut oak)	Common on higher ridges and young terraces	Weakly tolerant	Moderately intolerant
Q. nigra (water oak)	Widely on loam ridges in first bottoms and any ridge and silty clay flats in second bottoms or terraces	Weakly tolerant	Intolerant
Q. nuttallii (Nuttall oak)	Widely on flats, low ridges, shallow sloughs, and swamp margins	Moderately tolerant	Intolerant
Quercus pagoda (cherrybark oak)	Widely on best loamy sites; predominately on older alluvium; occasionally on tight, silty clay, flats and low ridges	Weakly tolerant	Intolerant
Quercus palustris (pin oak)	Similar sites as Nuttall oak in northern LMAV	Intermediate	Intolerant
Q. phellos (willow oak)	Widely on ridges and high flats	Moderately tolerant	Intolerant
Q. shumardii (Shumard oak)	Good ridge soils in older alluvium and washout from uplands	Weakly tolerant	Intolerant
Quercus stellata var. *mississippiensis* (Delta post oak)	Well-drained silty clay and loam sites on older alluvium	Weakly tolerant	Moderately intolerant

[a]See Stanturf and Schoenholtz (1997) for a discussion of terms used to describe sites.
[b]Intermediate indicates between intolerant and tolerant.

to choose appropriate species for mixed-species plantations (Ashton et al. 2001).

Tree form represents the combination of the genetically determined, inherent tree architecture and the effects of environmental influences that occur during a tree's development (Barnes et al. 1998). Excurrent tree form is an expression of strong apical control of the terminal leader over lateral branches, resulting in a narrow, conical crown shape (Barnes et al. 1998). Decurrent tree form results from weak apical control of the terminal leader over lateral branches, resulting in a broad, spreading tree crown (Barnes et al. 1998). Most bottomland hardwood species have a decurrent tree form but exhibit an excurrent form when competing with other stems in dense, young stands. As dominance is exerted through time, these species will shift to a decurrent form (Oliver and Larson 1996).

The pattern of early height growth indicates how rapidly a young tree can grow to attain or maintain a dominant or codominant canopy position during early stand development. We used four relative levels of early height growth based on information from Burns and Honkala (1990) and our personal observations: rapid, fast, medium, and slow. These levels are based on development of open-grown trees during the first 1–5 years of growth relative to the development of oak seedlings and saplings.

Branching pattern represents the arrangement of leaves and twigs for a given tree species. In bottomland hardwood species, 2 patterns are recognized: alternate and opposite. Branching pattern is important to early stand development because of the rate of apical dominance recovery following terminal damage. We hypothesize that a species with an alternate branching pattern can respond more quickly to maintain canopy position following breakage of the terminal by adjacent, competing trees. A species with an opposite branching pattern is slower to respond following terminal breakage since branches, which normally emerge at 45 to 90 degree angles from the main stem, take time to "curve" up toward the canopy opening.

Relative twig diameter and durability are a reflection of the strength of 1- to 2-year-old tree branches in the upper canopy. Relative twig diameter and durability is considered an important characteristic in stand development due to severe crown abrasion that occurs during strong winds associated with frontal storm systems and periodic tropical storms (Oliver and Larson 1996). In general, the larger a tree's twig diameter, the more durable it is to withstand breakage during crown abrasion. Moreover, relatively large twig diameter trees can potentially inflict much damage to the crowns of competing species.

Shoot type refers to the pattern of leaf production and stem growth that occurs on a tree during a growing season (Kramer and Kozlowski 1979). For example, determinate species typically have one flush of leaves and shoot growth at the beginning of the growing season. No further shoot growth occurs until the next growing season. Indeterminate species continually produce new leaves and shoot growth throughout the growing season. The rate of leaf production and shoot growth are determined by environmental conditions. A third shoot type, recurrent shoot growth, involves the production of one flush of leaves and shoot growth at the beginning of the growing season, but if environmental conditions are favorable, a second flush of growth will occur following a period of no shoot elongation. This recurrent pattern continues throughout the growing season as long as environmental conditions are favorable. Shoot types generally correlate with early height growth patterns, in that indeterminate species will often have rapid early height growth while determinate species will have slower early height growth.

Information on successional status is needed to choose species for mixed-species plantations (Ashton et al. 2001). Successional status reflects the type of community in which a tree species is commonly found. Three successional states are recognized following successional pathways developed by Hodges (1997) for bottomland hardwood ecosystems: early, mid, and late.

Species Consideration

An assumption of the system is that oak species and nonoak species will be planted concurrently to create a single-cohort, mixed-species stand. Mixed-species prescriptions involving oaks and nonoaks in delayed planting schemes, leading to the development of double-cohort, mixed-species stands, are currently being developed (Gardiner et al. 2004). However, development of multicohort stands is beyond the scope of this work. A second assumption of the

Table 2. Nonoak species commonly found in the Lower Mississippi Alluvial Valley (LMAV) along with their respective silvical characteristics.

	Flood tolerance	Shade tolerance	Tree form	Early height growth pattern	Branching pattern	Relative twig diameter and durability	Shoot growth pattern	Successional status
A. negundo (boxelder) Riverfront, particularly on ridges or high flats of new alluvium	Moderately tolerant	Moderately tolerant	Decurrent	Fast	Opposite	Medium	Indeterminate	Early to mid
A. rubrum (red maple) Scattered widely on high ridges and deep swamps; most common in low situations and heavy soils, especially on old alluvium	Moderately tolerant	Tolerant	Decurrent	Fast	Opposite	Medium	Indeterminate	Mid
A. saccharinum (silver maple) Riverfronts and banks	Moderately tolerant	Intolerant	Decurrent	Fast	Opposite	Medium to small	Indeterminate	Early to mid
Carya aquatica (water hickory) Common on flats, sloughs, and margins of swamps; occasionally on low clay ridges	Moderately tolerant	Tolerant	Decurrent	Slow	Alternate	Large, stout	Determinate	Mid to late
Carya glabra (pignut hickory) Most abundant on upland slopes and ridges; occasionally on low ground	Weakly tolerant	Tolerant	Decurrent	Slow	Alternate	Large, stout	Determinate	Late
C. illinoinensis (sweet pecan) Largely restricted to present or recent riverfronts on loamy soils (never on old alluvium)	Weakly tolerant	Moderately intolerant	Decurrent	Medium	Alternate	Large, stout	Determinate	Mid
Carya ovata (shagbark hickory) Occurs on deep, moist soils of alluvial origin	Intolerant	Intermediate	Decurrent	Slow	Alternate	Large, stout	Determinate	Late
C. laevigata (sugarberry) Widely except in deep swamps; most common on flats and riverfronts of new alluvium	Moderately tolerant	Very tolerant	Decurrent	Slow to medium	Alternate	Small	Determinate	Late
D. virginiana (common persimmon) Scattered widely on wet flats, shallow sloughs, and swamp margins	Moderately tolerant	Very tolerant	Decurrent	Medium	Alternate	Medium	Determinate	Early to mid
F. pennsylvanica (green ash) Widely distributed on new sediments and in first bottoms except deep swamps; most common on flats and shallow sloughs	Moderately tolerant	Moderately tolerant	Excurrent	Fast	Opposite	Medium	Indeterminate	Mid
Fraxinus profunda (pumpkin ash) Widely scattered along swamp margins and river bottoms; found on wet to very wet sites	Tolerant	Intermediate	Excurrent	Fast	Opposite	Medium	Indeterminate	Mid
G. triacanthos (honeylocust) Scattered widely except in sloughs and swamps; most common on better ridges of new alluvium	Moderately tolerant	Intolerant	Decurrent	Fast	Alternate	Medium	Determinate	Early
L. styraciflua (sweetgum) All but the wettest sites; best development generally on clay loam ridges of newer alluvium	Moderately tolerant	Intolerant	Decurrent	Fast	Alternate	Medium	Indeterminate	Early
N. aquatica (water tupelo) Almost exclusively in swamps	Tolerant	Intolerant	Decurrent	Medium	Alternate	Medium	Determinate	Early
N. sylvatica (blackgum) Terraces	Weakly tolerant	Moderately intolerant	Decurrent	Slow	Alternate	Medium	Determinate	Mid to late
P. occidentalis (American sycamore) Widely on fronts; on bare areas and washes of light, moist soils	Moderately tolerant	Very intolerant	Decurrent	Rapid	Alternate	Large	Indeterminate	Early
P. deltoids (eastern cottonwood) Widely distributed, mostly on newly deposited soils	Moderately tolerant	Very intolerant	Excurrent	Rapid	Alternate	Large	Indeterminate	Early
Populus heterophylla (swamp cottonwood) Widely scattered in shallow swamps, deep sloughs, and often-flooded stream bottoms	Tolerant	Moderately intolerant	Excurrent	Rapid	Alternate	Large	Indeterminate	Early
S. nigra (black willow) Fronts, mud flats, swamp margins	Tolerant	Very intolerant	Excurrent	Rapid	Alternate	Small	Indeterminate	Early
S. albidum (sassafras) Higher ridges and terraces	Intolerant	intolerant	Excurrent	Fast	Alternate	Small to medium	Determinate	Early to mid
T. distichum (baldcypress) Swamps, deep sloughs, borders of old lake beds; poorly drained flats	Tolerant	Moderately intolerant	Excurrent	Fast	Alternate	Small	Determinate	Early
U. Americana (American elm) Widely, except in deep swamps; especially on flats in newer alluvium	Moderately tolerant	Intermediate	Decurrent	Fast	Alternate	Small	Determinate	Early to mid
U. crassifolia (cedar elm) Widely on high flats or poorly drained low ridges; usually on impervious silty clay soil	Moderately tolerant	Intermediate	Decurrent	Fast	Alternate	Small	Determinate	Early to mid

See text for explanation of columns.

system is that an objective in single-cohort, mixed-species afforestation planting schemes, whether of primary or secondary importance, is the development of quality oak boles. Quality oak boles are defined as trees with a grade 1 sawlog or the potential to develop a grade 1 sawlog (Kenna 1981, 1994). Furthermore, it is assumed that oaks will not develop quality boles unless they attain a dominant or codominant position in the upper forest canopy (Meadows et al. 2001). The development of quality boles and attainment of crown dominance will result in large, valuable oak trees that will increase options for future stand management decisions.

Putnam et al. (1960) listed 20 oak species commonly found in bottomland hardwood ecosystems across the southeastern United

Table 3. Point values assigned to specific properties in each of five categories used to determine potential nonoak species to plant in mixtures with oak species.

Category	Characteristic	Assigned point value
Tree form	Excurrent	15
	Decurrent	10
Early height growth pattern	Rapid	10
	Fast	30
	Medium	20
	Slow	10
Branching pattern	Alternate	15
	Opposite	5
Relative twig diameter and Durability	Large	10
	Medium	30
	Small	30
Shoot type	Indeterminate	10
	Determinate	5

States. Nine of these species, plus two less common oak species, are indigenous to the LMAV (Table 1). These species occur on a variety of sites in the LMAV, depending primarily on tolerance to frequency and duration of flooding. Three of the species, Nuttall (*Quercus nuttallii* Palmer), willow (*Quercus phellos* L.), and water (*Quercus nigra* L.), are the oak species most commonly planted on afforested sites in the LMAV (Schoenholtz et al. 2001).

Putnam et al. (1960) and Lockhart et al. (2005) listed 67 other tree species found in bottomland hardwood ecosystems across the southeastern United States, and about 40 of these species occur in the LMAV. Table 2 lists 24 of these species that regularly attain an overstory canopy position in mature bottomland hardwood stands in the LMAV. The exclusion of understory tree species from Table 2 does not reduce their important role in bottomland hardwood ecosystem functions (Lockhart 2004).

System Function

We developed a system using nonoak species that may be suitable for planting with oak species based on five of the categories in Table 2: tree form, early height growth pattern, branching pattern, relative twig diameter and durability, and shoot type. Points were assigned based on the species characteristics (Table 3). Two categories in Table 2 were considered more important regarding their influence during early interspecific competition between oak and nonoak species; therefore, their point values were doubled for each characteristic. Two further adjustments were made to the point assignments in Table 3. First, rapid early height growth was reduced because this characteristic could result in suppression of planted oaks with little chance for survival. Likewise, the point value for large diameter twigs was reduced because species with this characteristic could also result in early suppression of planted oaks through crown abrasion. We used sweetgum as the model nonoak species in developing these categories and scaling criteria. Sweetgum has been shown to be an excellent species for providing the training benefits of interspecific competition in the development of quality oak trees in both natural stands (Clatterbuck et al. 1985, Clatterbuck and Hodges 1988) and mixed-species plantations (Lockhart et al. 2006).

A maximum score for the ideal species to plant in an intimate mixture with oak species, depending on site conditions, is 100. Sweetgum, because it was used as the model nonoak species, scored a 100 (Table 4). One other species that occurs in southern floodplains, river birch (*Betula nigra* L.), also scored a 100 but this species rarely occurs within the LMAV. Six species scored 90 or more—green ash, pumpkin ash (*Fraxinus profunda* [Bush] Bush), honeylocust (*Gleditsia triacanthos* L.), baldcypress (*Taxodium distichum* [L.] L. C. Rich.), American elm (*Ulmus americana* L.), and cedar elm (*Ulmus crassifolia* Nutt.). Seven species scored point values of 80 or 85—boxelder (*Acer negundo* L.), red maple, silver maple (*Acer saccharinum* L.), common persimmon (*Diospyros virginiana* L.), water tupelo (*Nyssa aquatica* L.), black willow, and sassafras (*Sassafras albidum* [Nutt.] Nees). Two species scored a 70—sugarberry (*Celtis laevigata* Willd.) and blackgum (*Nyssa sylvatica* Marsh.), while the remaining species scored 60 points or less.

Potential Species Mixtures

All species listed in Table 2 could serve as compatible species for planting with oaks in intimate mixtures in the LMAV despite their score in the conceptual model (Table 4). Several of these nonoak species would require alternative spacing arrangements from the normal spacing arrangement (12 × 12 ft) or require early silviculture treatment, otherwise they could suppress oaks during normal stand development. Other nonoak species would be quickly overtopped by oaks, thereby providing little training benefit through interspecific competition.

The *Acer* species scored well (85 points) as potential species to use with oaks in plantation mixtures in the LMAV. These species have fast early height growth along with medium-sized twig diameters to provide an early height advantage relative to oak species without overtopping them in normal plantation spacing. Boxelder occurs on higher sites within the floodplain on recent alluvium, sites that also support water oak and Shumard oak (*Quercus shumardii* Buckl.). Red maple occurs primarily on lower sites with clay soils; therefore, it would be an ideal species to plant in mixtures with Nuttall and willow oaks, possibly even overcup oak (*Quercus lyrata* Walt.). Red maple has been shown to be an excellent training species for northern red oak in upland New England hardwood forests (Oliver 1978). Silver maple is found primarily on recent alluvium in the most northerly area of the LMAV; therefore, its use as a potential species in mixtures may be limited to these areas.

The *Carya* species, as a whole, did not score well as potential plantation mixtures with oak species (Table 4). The disadvantage to using *Carya* species as interspecific competition with oaks is their relatively slow early height growth. Although each of the *Carya* species has large, stout twigs, these are not a factor in competing with oaks because *Carya* species would be quickly overtopped by oak species. Although the conceptual model presented in Table 3 was developed specifically for oaks, we see the potential use of this model in identifying species that could be planted in mixtures with *Carya* species. *Carya* species, especially sweet pecan, are often used in plantings in the LMAV to provide a nonoak hard mast species for wildlife. Sweet pecan may also have high timber value depending on local market conditions.

Other species that scored well include members of the genus *Fraxinus*. Green ash and pumpkin ash each scored 90. Green ash is often mentioned as a substitute for sweetgum in plantation mixtures with oak species in the LMAV. It occurs on a variety of sites throughout the LMAV except in deep swamps, has fast early height growth, is readily available from commercial seedling nurseries, and is a highly valued timber species. Unfortunately, our personal observations have shown that green ash, when found in young, natural, mixed-species stands, is often overtopped by oaks as early as age 5 years. One explanation may be its opposite branching pattern, whereby removal of the terminal through crown abrasion results in

Table 4. Point values by category for 24 nonoak species in the Lower Mississippi Alluvial Valley.

Species	Tree form	Early height growth pattern	Branching pattern	Relative twig diameter and durability	Shoot growth pattern	Total
Boxelder	10	30	5	30	10	85
Red maple	10	30	5	30	10	85
Silver maple	10	30	5	30	10	85
Water hickory	10	10	15	10	5	50
Bitternut hickory	10	20	15	10	5	60
Pignut hickory	10	10	15	10	5	50
Sweet pecan	10	20	15	10	5	60
Shagbark hickory	10	10	15	10	5	50
Sugarberry	10	10	15	30	5	70
Common persimmon	15	20	15	30	5	85
Green ash	15	30	5	30	10	90
Pumpkin ash	15	30	5	30	10	90
Honeylocust	10	30	15	30	5	90
Sweetgum	15	30	15	30	10	100
Water tupelo	15	20	15	30	5	85
Blackgum	10	10	15	30	5	70
American sycamore	10	10	15	10	10	55
Eastern cottonwood	15	10	15	10	10	60
Swamp cottonwood	15	10	15	10	10	60
Black willow	15	10	15	30	10	80
Sassafras	15	20	15	30	5	85
Baldcypress	15	30	15	30	5	95
American elm	10	30	15	30	5	90
Cedar elm	10	30	15	30	5	90

a delayed reaction to maintain upper canopy stature, resulting in green ash being quickly overtopped. In a plantation setting, where green ash would be planted farther away from oak species than spacings found in natural stands, it may provide the early training effects of interspecific competition before oaks finally surpass it during normal stand development. Green ash theoretically could be planted with any of the bottomland oak species listed in Table 1. Pumpkin ash is typically found on wet to very wet sites; therefore, it would be beneficial only to oaks that occur on similar sites, such as Nuttall and overcup.

Two additional species that scored 90 or more include baldcypress and honeylocust. Baldcypress is typically thought to grow only in swamps and poorly drained low flats, but baldcypress can grow well on moist, loamy ridges. Because of its shade-intolerant nature, it would require intensive herbaceous competition control on these latter sites until it became well established. Its excurrent tree form may provide similar interspecific competition to oaks as does sweetgum. Theoretically, a variety of oaks can be mixed with baldcypress, depending on site conditions. Honeylocust is commonly found on young ridges. Its fast early height growth and medium twig diameter make it an ideal candidate for mixtures with oaks. However, few oak species are found on new alluvium because of its basic soil pH (Hodges 1997). Water and Shumard oaks may be the best candidate species to mix with honeylocust.

Ulmus species may also serve as good trainer trees for oak species in a plantation mixture. American elm and cedar elm both scored 90 (Table 4). American elm occurs on a variety of sites in the LMAV, especially on flats in newer alluvium, and cedar elm occurs primarily on poorly drained, clay soils; therefore, these species could be planted with most of the oaks that occur in the LMAV. American elm could be mixed with water and willow oaks, while cedar elm would be a potential candidate for mixing with Nuttall and overcup oaks.

Water tupelo also scored well with an 85 (Table 4). However, water tupelo occurs almost exclusively in swamps, sites where oaks do not occur. Unlike baldcypress, the performance of water tupelo on sites outside of swampy areas is presently unknown; therefore, we cannot make planting mixture recommendations at present with water tupelo and oaks. Common persimmon, which also scored an 85 (Table 4), is noted for invading former agricultural fields via seeds dispersed by animals. We have observed good growth in these situations, but in natural stands, common persimmon is often outcompeted by other oak and nonoak species. We speculate that its twigs, although medium in relative size, have weak durability and easily succumb to crown abrasion. In a plantation setting, it may provide very early interspecific competition benefits up to crown closure at age 5–10 years. Sassafras, another species that scored an 85, occurs on relatively higher sites with older alluvium in the LMAV. It could serve as a potential trainer tree for oaks that grow on similar sites, e.g., cherrybark, swamp chestnut (*Quercus michauxii* Nutt.), and water oaks.

The remaining species in Table 4 scored 80 points or lower. Black willow, American sycamore, eastern cottonwood, and swamp cottonwood are typically pioneer species. Their rapid early height growth, in some cases 10 ft yr^{-1} the first 2–3 years after establishment, would quickly overtop planted oaks under typical plantation spacings. Black willow and eastern cottonwood are the first species to occupy recently developed mudflats and sandbars, respectively, formed by river channel migration (Hodges 1997). Black willow, with its small twig size and short-lived nature, may be a suitable species for mixing with oak species, but may require a slightly larger plantation spacing, possibly 15 × 15 ft. In a single-cohort, mixed-species arrangement, eastern cottonwood would either have to be planting at wider spacings or require early thinning to keep from overtopping planted oaks. Similarly, American sycamore has been shown to overtop cherrybark oak in a 12 × 12 ft plantation spacing (Clatterbuck et al. 1987). Oaks that were planted in the third row from a row of American sycamore (36 ft away) were able to develop into overstory canopy trees. Therefore, using American sycamore in intimate plantation mixtures with oaks will also require wider planting distances or early thinning to maintain oak development.

Sugarberry (*C. laevigata* Willd.) and blackgum (*N. sylvatica* Marsh.) are common, shade-tolerant, understory species that can grow into overstory trees. They each scored 70 on the conceptual model (Table 4). Their slow early height growth would not provide the early benefits of interspecific competition to the various oak species found in the LMAV.

Spacing and Arrangements Considerations

The typical spacing arrangement in afforestation operations in the LMAV is 12 × 12 ft. To increase the beneficial effects of early interspecific competition on the development of oaks, some recent plantations are being established on a 10 × 12-ft spacing with a variety of species mixtures. To maximize the training effects of early interspecific competition of nonoak species on oak species, we recommend even closer spacing arrangements, e.g., 10 × 10 ft or even 8 × 8 ft. Lockhart et al. (2006) showed that planted cherrybark oak was able to stratify above planted sweetgum at 8 × 8-ft and 5 × 5-ft spacings by age 21 years. These closer spacings will increase initial stem density, thereby promoting quicker crown closure, earlier interspecific competition, and more pronounced training effects of the nonoak species on oak species (Oliver and O'Hara 2005). A greater number of stems will also provide for more management options as the stand develops. For example, forest resource managers will have a greater number of stems from which to select "crop" trees that meet explicit management objectives. Assessment of intimate plantation mixtures suggests that rows of nonoak species be planted adjacent to rows of mixed nonoak and oak species, resulting in individual oak trees surrounded by nonoak trees. Planting pure rows of nonoak species adjacent to pure rows of oak species would increase planting efficiency but would reduce interspecific competition and result in early intraspecific competition between oaks. Interspecific oak competition should be avoided until after the oaks have stratified above nonoak species and have begun competing in the upper canopy (Kittredge 1988). A greater number of individuals of the nonoak species, especially after oak stratification, will also provide a greater midstory canopy component for wildlife habitat (Twedt and Best 2004) or biomass for pulpwood or biofuel production.

As forest restoration advances in the LMAV, an important step in the evolution of afforestation practices will have to focus on the establishment of species mixtures to more closely emulate natural stand conditions. Notable examples of young mixed-species plantations exist in the LMAV, but they were planted with little knowledge of stand development patterns, specifically the competitive effects each species has on other species, especially oaks. Because of limited research knowledge and practical experience regarding mixed-species plantations and their subsequent development in the LMAV, we developed a system of potential species to mix with oaks based on silvical characteristics and personal observations. This system is not designed as a substitute for actual mixed-species planting trials, but such research will take 20–30 years to provide useful results.

Planting many of the nonoak species will require forest resource managers to overcome inherent biases. Often, many of these species are considered "weeds" in forest management, based on timber management objectives in other forest cover types. As we learn more about how mixed-species bottomland hardwood stands develop, we gain a better understanding of the importance of nonoak species in the development of oak stands and their inherent functions to other aspects of floodplain forest ecosystems. In addition, this system has worldwide applicability as a tool to screen species for planting in mixtures in the absence of data from earlier plantation mixtures. The system does require knowledge of individual species silvics and patterns of development in natural stands. The categories used in Table 2 may not be applicable to other forest cover types, but represent a way of thinking to improve afforestation practices.

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