The Great Trinity Forest Management Plan

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Stand Development Patterns in Southern Bottomland Hardwoods: Management Considerations and Research Needs

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STAND DEVELOPMENT PATTERNS IN SOUTHERN BOTTOMLAND HARDWOODS: MANAGEMENT CONSIDERATIONS AND RESEARCH NEEDS

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Abstract: Stand development involves changes in stand structure over time. Knowledge of stand development patterns is crucial for effective forest management, especially of southern bottomland hardwood forests. These forests contain more than 70 tree species, many of which have commercial timber and wildlife habitat value. In this paper, current techniques in stand development research are reviewed. Emphasis is placed on stand development studies in bottomland red oaks (*Quercus* spp.), especially cherrybark oak (*Q. pagoda*), although examples from other oak forest types are included. These studies were divided into 3 broad categories: pure, single-cohort stands; mixed, single-cohort stands; and mixed, multi-cohort stands. Management implications based on these development patterns are discussed, including the importance of many of the non- or less-commercial species during stand development. Areas for future research also are suggested to increase the knowledge base on bottomland hardwood stand development.

Key Words: bottomland hardwoods, cherrybark oak, chronosequence, reconstruction, stand development.

Stand development involves changes in stand structure over time (Oliver and Larson 1996). These changes occur in a horizontal sense, or distribution of trees by species and diameter, and in a vertical sense, or distribution of tree heights, within a stand (Kittredge 1986). An understanding of how bottomland hardwood stands develop is essential for long-term management of these forests for their various functions (including wildlife habitat and nutrient retention) and values (including water quality maintenance, recreational opportunities, and wood production capabilities). The objectives of this paper are to: (1) provide an overview of basic stand development research techniques, (2) provide a synopsis of bottomland hardwood stand development research and applicable upland hardwood stand development research, (3) relate these stand development patterns to possible silvicultural practices for both quality sawlog production and wildlife habitat, and (4) develop a list of research priorities for increasing our knowledge of bottomland hardwood stand development and summarize the current status of ongoing stand development research.

STAND DEVELOPMENT RESEARCH TECHNIQUES

An understanding of stand development patterns, management implications, and possible research opportunities requires a knowledge of basic stand development research techniques. Oliver (1982) listed 5 techniques used in stand development research: chronosequence, reconstruction, permanent plots, observation of tree physiological characteristics, and observation of existing stand physiognomy. Three of these techniques are pertinent to this paper to understand results from the stand development studies presented in the next section.

Chronosequence

A chronosequence consists of a series of stands of different ages, but on similar sites, that are assumed to have been similar in species composition and structure at a given age (Clatterbuck and Hodges 1988). Such stands can be used to represent different ages of the same stand development pattern (Oliver 1982). Advantages of using a chronosequence include the ability to move forward and backward along a time/stand development gradient. This technique also allows the study of stand development patterns over a relatively short period of time. However, it is difficult to locate stands growing on similar sites with similar disturbance histories, species compositions, and spatial distribution and age distribution patterns (Oliver 1982). The need for homogeneous

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sites is especially important for stands growing on floodplains of meandering streams and rivers given the heterogenous nature of the landscape (Putnam et al. 1960, Hodges and Switzer 1979).

Reconstruction

Stand reconstruction, or stem analysis, involves tracing the growth of individual trees backward in time. This is usually accomplished by aging and measuring growth of increment cores and/or stem cross-sections cut at intervals from felled trees. Advantages of this method include the ability to study stands which are currently in a desirable form (Oliver 1982). Reconstruction, though labor intensive, also requires only a small sample size to effectively determine development patterns. A drawback of this method though is the inability to detect the presence of species and individual trees that have disappeared during stand development up to the time of sampling. Reconstruction also requires destructive sampling; therefore, development of individual trees cannot be followed into the future. Safety considerations in operating a chainsaw and felling trees also must be considered.

Permanent Plots

The permanent plot technique consists of establishing plots for the purpose of re-measuring desired tree and stand characteristics over time. Permanent plots are the most accurate technique available for studying stand development patterns. This accuracy is due to having baseline data containing reliable trends of developmental patterns. Advantages include: (1) direct measurement of changes in tree and stand development, rather than inferring changes that could be attributed to differences in site, disturbance, or species composition; (2) precise documentation of mortality; and (3) easy recording of tree growth without the need for destructive sampling (Oliver 1982). Disadvantages include the length of time (usually several decades) and expense required before useful information on stand development patterns can be obtained. Furthermore, such a long-term project will be subject to administration and measurement by different people, thus possibly introducing biases, especially in height measurements.

In summary, the chronosequence, reconstruction, and permanent plot techniques each provide valuable information in trying to decipher stand development patterns. Because each of these techniques has its own advantages and disadvantages, stand development studies usually involve various combinations and refinements of these techniques along with stand-history information to gain more insight into changes in stand structure.

STUDIES OF BOTTOMLAND HARDWOOD STAND DEVELOPMENT

Few studies have been conducted on bottomland hardwood stand development, focusing primarily on red oak species. Research into bottomland hardwood stand development patterns can be divided into 3 categories: (1) pure, single-cohort stands, (2) mixed, single-cohort stands, and (3) mixed, multi-cohort stands.

Pure, Single-Cohort Stands

Pure, single-cohort stands (even-aged stands composed of 1 species) are relatively rare in bottomland hardwood forests. Specific examples include cottonwood (*Populus deltoides*) or black willow (*Salix nigra*) stands on newly formed land near major river systems (Hodges and Switzer 1979), baldcypress (*Taxodium distichum*) or water tupelo (*Nyssa aquatica*) growing in sloughs and swamps (Hodges and Switzer 1979), and relatively pure red oak stands (pure in the sense of a single genus) that grow on poor-quality flats or follow specific disturbances including fire, grazing, and/or mowing (Aust et al. 1985).

Johnson and Burkhardt (1976) used the chronosequence technique to observe that natural cottonwood stands initially establish in large numbers, e.g., thousands of stems per acre. At such densities, stagnation of the stand would seem likely. But Johnson and Burkhardt (1976) indicated that individual cottonwood trees express dominance by age 3 or even earlier. Dominant cottonwoods quickly overtop neighboring cottonwood trees resulting in a stratified stand rather than a stagnated stand. Stratification through early intra-specific competition (competition within a species) was due to the large genetic diversity among cottonwood trees (Johnson and Burkhardt 1976). This development pattern resulted in more desirable trees for quality sawlog production than that associated with pure cottonwood plantations.

The occurrence of single-genus, single-cohort stands of bottomland red oak is believed to be the result of fortuitous events early in the life of the stand, such as fire, grazing, and/or mowing that eliminated competing species (Aust et al. 1985). While pure stands of water oak (*Q. nigra*) and willow oak (*Q. phellos*) can be found on poorly-drained flats (often called pin-oak flats), pure stands of cherrybark oak occur much less frequently. Studies of how such stands develop provide useful insight into how bottomland red oaks interact when confronted with intra-specific (or intra-genus) competition throughout their life. At present, only 1 study has been conducted on stand development in natural single genus stands of bottomland red oaks.

Aust (1985) used the chronosequence technique to identify factors important in determining stand structure in relatively pure red oak stands. Stratification in these pure stands differed from that of mixed-genus, single-cohort stands. In single-genus, natural red oak stands, increased intra-specific (or intra-genus) competition among oaks may result in individual trees growing taller with lower live-crown percentages as compared to oaks from mixed stands. Such a development pattern is common in cottonwood (Johnson and Burkhardt 1976) and loblolly pine (*Pinus taeda*) (Guldin and Fitzpatrick 1991) stands. These conditions could lead to increased lengths of branch-free boles through continual natural pruning by neighboring oak stems as with pure cottonwood stands. Kittredge (1986) found that the height to the base of the main fork in individual red oaks was positively related to the amount of northern red oak present in pre-stratified, mixed stands, which suggests that intra-specific competition early in a stand's development produced longer merchantable bole lengths. But similar results were not found by Aust (1985) in pure bottomland red oak stands under either narrow or wide spacing between oak stems. Furthermore, early intra-specific competition between bottomland red oaks may increase stress within individual oaks, possibly increasing the probability of epicormic branching and lowering of bole quality (Meadows 1995). Early intra-specific competition may also reduce crown area with a possible decrease in mast production.

Mixed, Single-Cohort Stands

Mixed, single-cohort stands (even-aged stands composed of 2 or more tree species or genera) are common in bottomland hardwood forests. Development of such stands typically results in stratified mixtures with each crown stratum being occupied by a different species or genus usually of different shade tolerances (Oliver and Larson 1996).

Clatterbuck and Hodges (1988) used a combination of the chronosequence and reconstruction techniques in mixed cherrybark oak-sweetgum (*Liquidambar styraciflua*) stands growing on old-field bottomland sites. Their results identified 3 patterns of cherrybark oak development depending upon the average spacing between a cherrybark oak and adjacent sweetgum during the pole stage of development. The patterns were "restricted," "unrestricted," and "overtopped."

In the restricted pattern of development, spacing between a cherrybark oak and neighboring sweetgum was approximately 6-18 feet (2-5.4 m). This spacing resulted in cherrybark oak being initially shorter than sweetgum. Then, 20-23 years after stand initiation, cherrybark oak overtopped sweetgum and emerged into the canopy overstory. Cherrybark oak emergence was the result of a decrease in the rate of sweetgum height growth along with an increase in the rate of cherrybark oak height growth. Clatterbuck (1985) suggested several reasons for this:

(1) Crown architecture. Sweetgum exhibits a narrow, excurrent crown form while cherrybark oak exhibits a semi-excurrent crown form when competing with sweetgum but changes to a decurrent, spreading, form after emergence into the overstory. The narrow crowns of sweetgum allow direct sunlight to reach cherrybark oak trees that may be 3-6 feet (1-2 m) shorter in height. This gives cherrybark oak trees the opportunity to reach the overstory with the sweetgum.

(2) Crown abrasion. Sweetgum twigs are thinner and more brittle at a given age as compared to cherrybark oak twigs; thus, during wind events (especially squall lines associated with frontal storms), terminal buds and twigs of sweetgum tend to break when scraped against twigs of neighboring cherrybark oak stems.

(3) High initial sweetgum density. A high initial sweetgum density may delay intra-specific (within species) crown differentiation, thus leading to stagnation of the sweetgum (Johnson 1968).

(4) Phenology. Bud break in cherrybark oak, though occurring several days later than in adjacent sweetgum, occurs basipetally from the top of the crown while bud break in sweetgum occurs acropetally beginning at the base of the crown (Young 1980). Early growth of cherrybark oak twigs at the top of the crown may give cherrybark oak a competitive advantage when competing with sweetgum, especially during events leading to crown abrasion.

In the unrestricted pattern of development, spacing between a cherrybark oak and neighboring sweetgum was greater than 18 feet (5.4 m) or the cherrybark oak was several years older than the sweetgum. Cherrybark oak, growing in these conditions, was essentially free-to-grow and thus experienced little crown competition from sweetgum following stand initiation. This condition is depicted in the height growth patterns in which cherrybark oak is always taller than adjacent sweetgum.

In the overtopped pattern of development, spacing between a central cherrybark oak and neighboring sweetgum was less than 6 feet (2 m). Under these conditions cherrybark oak stems were subordinate to adjacent sweetgum and stood little chance for survival (Clatterbuck 1985).

We speculate that a comparison of the restricted and unrestricted patterns would show that the distance of neighboring sweetgum, i.e., the amount of inter-specific (between species) competition, affects the carbon allocation patterns of cherrybark oak. With relatively small distances to neighboring sweetgum, more photosynthates would be allocated to height growth as the oak tree competed for dominance; a survival mechanism. After emergence, or stratification, cherrybark oak height growth rate would slow but crown and basal area, or diameter, growth would increase. This change reflects the spreading habit of emergent oak crowns which increases leaf area, thus leading to greater photosynthate production.

The spreading habit of oak crowns following stratification has been noted by Kittredge (1988). This study, involving mixed stands of northern red oak, black birch (*Betula lenta*), and red maple (*Acer rubrum*), combined the reconstruction and chronosequence techniques. Stands chosen were approximately 40-60 years of age, a time in which northern red oak had recently stratified above birch and maple. Stands differed primarily in the density of oak present in the overstory. Because cherrybark oak and northern red oak may have similar patterns of development (Hodges and Janzen 1987), this study may shed light on bottomland red oak development as well.

Kittredge (1988) found that the number of trees, primarily black birch, red maple, and red oaks, within a 32.8-foot (10 m) radius of a northern red oak tree did not have a negative impact on 5-year basal area growth. On the other hand, the amount of oak basal area and number of oak trees within the same 32.8-foot (10 m) radius had a significantly negative effect on the northern red oak tree basal area growth. Total basal area also had a negative effect on central oak basal area growth but to a lesser extent than neighboring oak basal area. The major reason for this growth reduction involved intra-specific competition between oak crowns in the upper canopy following stratification. Crown expansion and subsequent basal area growth of individual oaks was greater in the presence of few oak competitors rather than many, a result of decreased intra-specific competition for growing space in the upper canopy. Kittredge (1986) suggested that this effect was due to: (1) wider crowns (lower oak density) have a greater surface area and are thus exposed to a higher quantity and quality of sunlight; (2) increased crown surface area in full sunlight produced a higher sun: shade foliage ratio and thus increased photosynthate production, and; (3) smaller crowns (higher oak density) have an increased incidence of crown abrasion with stout twigs of neighboring oaks and possibly within individual crowns itself. Therefore, an individual oak will allocate more photosynthate defensively to branch thickening at the expense of bole thickening.

Clatterbuck and Hodges (1988), Kittredge (1988), and Oliver (1976) demonstrated the phenomenon of oak stratification in mixed stands through the chronosequence and reconstruction techniques. But only 1 study has given unequivocal evidence to bottomland red oak stratification through use of the permanent plot technique.

Johnson and Krinard (1988) found that 28 years after stand initiation, bottomland red oak species (cherrybark, water, and willow oaks) began to emerge above sweetgum. They stated this situation was hardly predictable after 9 years when the overstory was composed primarily of sweetgum, river birch (*Betula nigra*), and American hornbeam (*Carpinus caroliniana*). During normal stand development, the river birch began to die due to increasing competition while the American hornbeam was relegated to an understory position. The authors postulated that red oak would exceed sweetgum in height within 30-35 years after stand initiation. The difference in time of stratification between this study and Clatterbuck and Hodges' (1988) study was probably due to the cutover sites utilized by Johnson and Krinard (1976, 1983, 1988) compared to the old-field sites utilized by Clatterbuck and Hodges. Similar results were reported by Bowling and Kellison (1983) in mixed stands of water oak, sweetgum, blackgum (*Nyssa sylvatica* var. *biflora*) and American hornbeam.

In summary, these studies suggest that cherrybark oak, and possibly water oak and willow oak, can reach a dominant or codominant position in mixed, single-cohort bottomland hardwood stands. If given some direct overhead sunlight during the early years of stand development, bottomland red oaks will eventually surpass species such as river birch, American hornbeam, and sweetgum through inter-specific competition. Once in the overstory, intra-specific (or intra-genus) competition among oaks plays a major role in regulating growth and development of individual oak trees. But recent studies in other mixed-genus stands have shown that cherrybark oak (and probably other bottomland red oaks) will not stratify above species such as sycamore (*Platanus occidentalis*; Clatterbuck et al. 1987), loblolly pine (Clatterbuck 1989), and yellow-poplar (*Liriodendron tulipifera*; O'Hara 1986) in stream and river floodplains.

The major differences between pure and mixed, single-cohort stands, in terms of growth and development of an individual red oak stem, are: (1) the timing and intensity of intra-specific and intra-genus competition among oaks and; (2) the lack of inter-specific competition in single-genus stands. Aust (1985) concluded that pure red oak stands had no major advantages or disadvantages over mixed-genus oak stands in terms of growth and yield. On the contrary, individual stems in mixed-genus stands will probably have larger crown and bole diameters. On a per-acre basis, fewer red oak stems of higher quality may produce more mast and be worth more economically than red oak stems grown in relatively pure stands. At present, this is speculative.

Mixed, Multi-Cohort Stands

Most research and management practices for bottomland hardwood stands have assumed that stands are even-aged (Hodges 1987). Development of uneven-aged stands has largely been neglected. This is due to several factors such as the relative scarcity of uneven-aged stands relative to even-aged ones, their more complicated stand structure, and even the sense that uneven-aged silviculture, in the strictest sense, in bottomland hardwoods is not viable (DeBell et al. 1968, Hodges 1987).

However, Guldin and Parks (1989) conducted a stem analysis study in an uneven-aged cherrybark oak stand. The study consisted of 0.2-acre plots, each of which contained 3 distinct age classes of cherrybark oak. Their data suggested that cherrybark oak stratification occurred within canopy gaps created by removal of large overstory trees. Two types of stratification were depicted. The first occurred within an age class, particularly the oldest age class, in which a single cherrybark oak seemed to dominate. The second type of stratification occurred between age classes. This was expected given that younger stems start below older stems. These stratification patterns do not take into account the effects of older, residual trees surrounding these gaps which should affect development within gaps.

Based on these results, Guldin and Parks (1989) stated that development of cherrybark oak in gaps might be similar to even-aged developmental dynamics as outlined by Clatterbuck and Hodges (1988). They also suggested that the absence of cherrybark oak in gaps created by single-tree and group selection cuts might be due to lack of sufficient advance oak regeneration at the time of harvest, rather than to the inability of existing advance growth to develop.

MANAGEMENT IMPLICATIONS

Management of bottomland hardwoods stands, especially red oak stands, is less complicated once stand development patterns have been recognized. Important considerations include species composition and ability of the forest resource manager to elucidate development patterns early in the stand development game, i.e., small-pole stage of development (4-6 inches dbh). If possible, desired trees should be identified at this stage. The following suggestions for bottomland hardwood management are based on neighboring species composition. These suggestions assume intermediate stand conditions; therefore, no consideration for regeneration is given. Also, biological maturity is assumed instead of economic maturity for rotation length due to an inherent bias for high-quality sawlogs and benefits of large trees for wildlife habitat.

Pure, Single-Cohort Stands

Development patterns in cottonwood result in an early stratification of dominants and codominants from the remaining trees. Thereafter, development of the dominant cottonwoods seems relatively unaffected by those that fall behind in height. Johnson and Burkhardt (1976) stated that "thinning does not increase gross volume production nor does it significantly improve the growth of individual dominant and codominant trees." So why thin? The benefits from thinning cottonwood stands revolve around capturing potential mortality and gaining economic benefits during the stand development process (Smith et al. 1997). Thinning also will increase forage production for wildlife. Plantation cottonwood apparently lacks the genetic diversity needed for stand stratification processes, resulting in potential stagnation of such stands. Therefore, thinning cottonwood plantations is more critical to development of desired individual trees than in natural stands.

Stratification in pure, single-cohort bottomland red oak stands differs from that in cottonwood stands. Red oaks apparently do not stratify as readily as pure stands of cottonwood, due possibly to less genetic diversity, differences in inherent growth patterns, crown shape, etc. The lack of inter-specific (or inter-genus) competition forces forest resource managers to rely on intra-genus competition to act as trainers of crop trees. This results in smaller crowns and bole diameters, maybe even lower bole quality, in crop trees. Therefore, several thinning operations may be needed to promote good growth of selected red oak crop trees. Such operations increase the risk of damage to both crowns and boles of crop trees. Thinning may also increase the incidence of epicormic branching, further lowering bole quality (Stubbs 1986, Meadows 1995).

Development of relatively pure bottomland red oak stands occurs in 1 of 2 situations. Poorly-drained flats usually contain species mixtures dominated by water oak and willow oak. These lower-quality sites cannot support high species diversity; therefore, development will progress as relatively pure red oak stands. Pure red oak stands on medium to high-quality sites are usually the result of disturbance early in the life of the stand (Aust et al. 1985), which should be avoided. Conventional wisdom suggests that it is better to have too much oak than none at all. But attempts should probably be made to control disturbances that promote establishment and development of relatively pure red oak stands, in favor of retaining mixed-species stands if large mast crops and high-quality sawlogs are the desired product. Cleaning or early thinning operations can especially be utilized to promote development of large crowns for wildlife habitat.

Mixed, Single-Cohort Stands

The key to managing red oak in mixed, single-cohort bottomland hardwood stands is the composition and spacing between neighbors and the crop tree, beginning with the small-pole stage of development. If neighboring trees are species such as American hornbeam, dogwood *(Cornus florida)*, sugarberry (*Celtis laevigata*), elm (*Ulmus* spp.), river birch or sweetgum, then bottomland red oaks (especially cherrybark oak) should stratify above these species. A common feature of these species is their inherent rapid early height growth that tapers off as individual species age. It is possible that stratification among these species and bottomland red oaks will occur in 2 stages. First, bottomland red oaks would stratify above those species whose height growth patterns decline early, such as American hornbeam and dogwood, which are then regulated to a subordinate canopy position or perish. Following a period of time, maybe as long as 20-30 years, bottomland red oaks would then emerge above species which slow in height growth at this time, such as river birch and sweetgum and possibly sugarberry and elms, and comprise the main canopy. Once the oaks have stratified above these species, crown expansion would begin leading to increased diameter growth. The limiting factor on diameter growth would then depend on the onset of intra-specific and intra-genus competition between oak crowns in the upper canopy.

Under this development scenario, deadening or thinning the competing species before the oaks gain dominance (a cleaning operation) would not be necessary, because the oaks will gain dominance regardless of these other species unless directly overtopped at an early age (Kittredge 1986). Results from understory vegetation control in a mixed-species hardwood stand in central Massachusetts, growing on a good site with adequate growing season soil moisture, showed no overstory oak growth response 13 years after treatment (Kelty et al. 1987). Thinning these "trainer" species may lower merchantable height and bole quality of the oaks thereby reducing their ultimate value. These trainer species also may act as a buffer for crop trees during future harvesting operations (Meadows 1996). Furthermore, these species increase the vertical structure of the stand, an important habitat feature for various bird species. An assumption of this management option of basically do nothing is that individual bottomland red oak stems attain some direct overhead sunlight throughout most of the early stages of their development. If wildlife habitat objectives revolving around large red oak crowns are of primary importance, then a cleaning operation combined with thinning among red oak stems would be needed to maximize red oak crown expansion.

If neighboring trees have inherent rapid height growth rates that continue to be high throughout much of the life of the tree compared to bottomland red oaks, such as yellow-poplar, sycamore, loblolly pine, and possibly green ash (*Fraxinus pennsylvanica*), it is less likely that bottomland red oaks can stratify above these species. Therefore, these species are the key competitors of bottomland red oaks. In the early stages of stand development it would be of benefit to the oaks if these key competitors were removed from the stand by deadening or harvesting. Because ash crown dynamics seem to be similar to that of oaks (Kittredge 1986), and given the current stumpage value for premium ash, stems of this species also may be considered as crop trees.

If neighboring trees are other oak species then spacing is especially critical. While the effects of other oak species competing with each other are not yet clear, it is reasonable to assume that intra-specific or intra-genus competition is more intense than inter-genus competition. If neighboring oak trees are relatively close to crop trees, but not close enough to compete before stratification above other species, then intra-specific competition will begin soon after stratification. This competition for space in the upper canopy will decrease growth of the crown, and thus the bole. Therefore, 2 options exist to either avoid or alleviate early intra-specific competition following stratification. One option is to deaden or pre-commercially thin some of the future oak competitors early in the life of the stand. This option is heavily dependent upon the forest resources manager's ability to pick crop trees at a young age. A second option is to conduct a crown thin following emergence of oak into the overstory. The purpose of this thinning operation is to reduce the number of emerging red oaks. Such an operation is risky given the destructive nature of harvest operations on residual crop trees, especially in relatively young, dense stands (Meadows 1993). If neighboring oaks are so close as to cause intra-specific competition early in the life of the stand, then development will be similar to that of a pure oak stand.

An optimum range of spacings between bottomland red oaks and its various neighboring species has yet to be determined except for cherrybark oak-sweetgum mixtures. Therefore, crop trees should be selected early in development of a mixed stand and neighboring composition identified. Species such as yellow-poplar, sycamore, and loblolly pine should be girdled or deadened if they will compete directly with the oaks in the future. Subsequent sprouts of the girdled hardwood species may not be able to compete starting underneath a small pole-sized stand. Many of the remaining species, i.e., those with slower rates of height growth compared to bottomland red oaks, should be left. These species will enhance development of the oaks by acting as "trainer" species while maintaining vertical canopy diversity.

Mixed, Multi-Cohort Stands

Management of bottomland red oak in uneven-aged stands is hampered by the scarcity of information about development of such stands. At present, it may be best to view red oak development in the gaps of uneven-aged stands as development of small, even-aged mixtures. Guldin and Parks (1989) noted that the trees developing within an individual gap were of relatively the same age. Because plots were selected for cherrybark oak, data also depicted intense intra-specific competition within a gap. Furthermore, these oaks probably competed with trees of older age classes with larger crowns surrounding the canopy gap. Therefore, red oak crop trees have 2 conditions of intra-specific competition, within a gap and from around the gap. While intra-specific competition within a gap may produce crop trees with smaller crowns, the periodic removal of trees around the gap may allow crop trees to spread their crowns. Therefore, such trees may have more desirable characteristics, such as large crowns, as compared to those grown in pure, single-cohort stands. Obviously, more information is needed on bottomland hardwood development in uneven-aged stands before more definite silvicultural prescriptions can be made.

FUTURE RESEARCH

There are many areas worthy of future research in stand development of southern bottomland hardwoods. What follows is a list briefly describing several of these areas.

Stand Development

Future stand development studies should use combinations of the chronosequence and reconstruction techniques to better understand development patterns. Variations of these techniques could include point-chronosequence using stands of similar ages but with varying amounts of oak density (similar to Kittredge 1988). Another variation could include using gaps of different ages as a chronosequence within a stand for studying development in uneven-aged stands. These studies should include the following situations: (1) different sites within floodplains, such as ridges and fronts on small river bottoms, and within the loessial hills; (2) different species compositions such as green ash, hickory (*Carya* spp.), etc., and; (3) varying densities of bottomland red oak species. In addition to using chronosequence and reconstruction techniques, efforts should be made to include permanent plots in the situations listed above.

Mixed-Species Plantations

At present, much effort is being expended on reforestation activities to convert former agricultural land to forest (Allen and Kennedy 1989). These activities involve establishing relatively pure bottomland oak stands or mixing several oak species. Based on reviews of previous stand development studies, such plantations may suffer in the long-run as oak trees of smaller crown dimensions and lower bole quality may be produced (unless such stands are judiciously thinned). Therefore, mixed-species stand development patterns need testing using artificial regeneration techniques, such as planting and direct seeding. Such plantations could potentially produce more biomass compared to single-species plantations as different species occupy different canopy layers (Kelty 1992). Greater vertical structure also will increase the number of niches available for various wildlife species. Results from a 17-year-old mixed cherrybark oak-sweetgum planting indicated that stand stratification processes can occur in hardwood plantations (Lockhart et al. 2000). Seven years following planting, sweetgum trees were taller and had greater diameters than associated cherrybark oak trees. By 17 years, no differences existed in height or diameter between the 2 species; essentially the cherrybark oak had caught up to the sweetgum. Another research effort studying mixed-species plantations and effects of intra-specific and inter-specific competition is underway using mixtures of Nuttall oak (*Q. nuttallii*), water oak, and green ash in an elaborate experimental design (Goelz 1995). Additional studies need to include other less-desirable species (from a timber standpoint) such as sweetgum, American hornbeam, sugarberry, hickories, and elms to determine if such species can contribute significantly to increased bole quality in addition to the added benefit of increased species diversity.

Crown Architecture

More study on the role of crown architecture in determining stand development patterns is warranted. Based on the previously discussed studies, the ability of a crop tree to compete successfully in the upper canopy depends on how well it can occupy physical growing space in the canopy. Future studies should include tests of relative twig and branch strength among species and how these relationships interact during wind events. Studies could also be conducted on crown expansion rates, foliage type (sun versus shade), and foliage distribution within a canopy.

Whole Tree Physiology

How well a crop tree competes ultimately depends on its ability to increase carbon allocation when more growing space becomes available. Therefore, information is needed on whole-tree leaf area and gas-exchange, i.e., net photosynthesis and transpiration. This information would not only increase knowledge on how bottomland red oaks grow but also provide insight into how they respond to competition from different species. Such a study has recently been completed with northern red oak, red maple, and black birch mixtures (Moser 1994).

Permanent Plots

While establishing more permanent plots to specifically study stand development would be desirable, the costs of such projects are probably prohibitive. Therefore, efforts should be made to expand data collection in existing bottomland hardwood growth and yield plots to encompass testing hypotheses about stand development. Furthermore, efforts should be made to retain permanent plot data, both growth and yield and continuous forest inventories, when long-term studies or inventories are terminated. Such data may contain as yet unrealized benefits regarding stand development patterns.

CONCLUSIONS

An understanding of how bottomland hardwood species develop is essential to making effective silvicultural recommendations for forest resource managers and landowners of bottomland hardwood forests. The fact that oaks can exist for decades beneath other species and yet can ultimately dominate the stand reflects the dynamic and robust nature of the genus. Recommendations for intermediate silvicultural treatments must reflect these unique developmental dynamics.

The fact that oak developmental dynamics are so different from those of the southern pines is part of the challenge for forest resources managers and landowners in the South. For example, if pines lag behind other species, they generally cannot recover. Forest managers who are accustomed to thinning and releasing pines from competing species at young ages might be tempted to apply similar tactics in young mixed-species bottomland hardwood stands -- and they might be making poor silvicultural decisions if they did.

The studies cited here epitomize how silvicultural recommendations must reflect the best scientific information available for the species being managed. Although forest resource management ultimately depends on the objectives of the landowner, it is up to the forest resources manager to advise on how to best meet these objectives. Finally, knowledge of stand development patterns is rewarding in itself, in simply knowing how a stand grows and in being able to predict how it will look in the future.

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LITERATURE CITED

Allen, J. and H. E. Kennedy Jr. 1989. Bottomland hardwood reforestation in the lower Mississippi valley. U.S. Fish and Wildlife Service and U.S. Forest Service, Southern Forest Experiment Station, New Orleans, LA.

Aust, W. M. 1985. The origin, growth, and development of natural, pure, even-aged stands of bottomland red oaks. MS Thesis, Mississippi State University.

_____, J. D. Hodges and R. L. Johnson. 1985. The origin, growth and development of natural, pure, even-aged stands of bottomland oak. Pages 163-170 *in* E. Shoulders, editor, Proceedings of the third biennial southern silvicultural research conference. U.S. Forest Service General Technical Report SO-54, (city & state).

Bowling, D. R. and R. C. Kellison. 1983. Bottomland hardwood stand development following clearcutting. Southern Journal of Applied Forestry 7:110-116.

Clatterbuck, W. K. 1985. Cherrybark oak development in natural mixed oak-sweetgum stands. Dissertation, Mississippi State University.

Clatterbuck, W. K. 1989. Even-aged mixtures of cherrybark oak and loblolly pine in southwestern Arkansas. Pages 123-127 *in* T. A. Waldrop, editor, Proceedings of pine-hardwood mixtures: a symposium on the management and ecology of the type. U.S. Forest Service General Technical Report SE-58, (city & state).

_____, and J. D. Hodges. 1988. Development of cherrybark oak and sweetgum in mixed, even-aged bottomland stands in central Mississippi, U.S.A. Canadian Journal of Forest Research 18:12-18.

_____, C. D. Oliver and E. C. Burkhardt. 1987. The silvicultural potential of mixed stands of cherrybark oak and American sycamore: spacing is the key. Southern Journal of Applied Forestry 11:158-161.

DeBell, D. S., J. Stubbs and D. D. Hook. 1968. Stand development after a selection cutting in a hardwood bottom. Southern Lumberman 217:126-128.

Goelz, J. C. G. 1995. Experimental designs for mixed-species plantations. Pages 559-563 *in* M. B. Edwards, Editor, Proceedings of the eighth biennial southern silvicultural research conference. U.S. Forest Service General Technical Report SRS-1, (city & state).

Guldin, J. M. and T. Parks. 1989. Development of cherrybark oak in an uneven-aged stand in west Tennessee. Pages 327-331 *in* J. H. Miller, editor, Proceedings of the fifth biennial southern silvicultural research conference. U.S. Forest Service General Technical Report SO-74, (city & state).

Guldin, J. M. and M. W. Fitzpatrick. 1991. Comparison of log quality from even-aged and uneven-aged-loblolly pine stands in south Arkansas. Southern Journal of Applied Forestry 15: 10-17.

Hodges, J. D. 1987. Cutting mixed bottomland hardwoods for good growth and regeneration. Pages 53-60 *in* Applying the latest research to hardwood problems, Proceedings of the 15th annual hardwood symposium of the hardwood research council. National Hardwood Lumber Association, Memphis, TN.

_____, and G. C. Janzen. 1987. Studies on the biology of cherrybark oak: recommendations for regeneration. Pages 133-139 *in* D. R. Phillips, editor. Proceedings of the fourth biennial southern silvicultural research conference. U.S. Forest Service General Technical Report SE-42, (city & state).

_____ and G. L. Switzer. 1979. Some aspects on the ecology of southern bottomland hardwoods. Pages 360-365 *in* North America's forests: gateway to opportunity. 1978 Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry, Bethesda, MD.

Johnson, R. L. 1968. Thinning improves growth in stagnated sweetgum stands. U.S. Forest Service Research Note SO-82, (city & state).

_____ and E. C. Burkhardt. 1976. Natural cottonwood stands — past management and implications for plantations. Pages 20-29 *in* B. A. Thielges and S. B. Land Jr., Proceedings: symposium on eastern cottonwood and related species. Louisiana State University, Division of Continuing Education, Baton Rouge.

_____ and R. M. Krinard. 1976. Hardwood regeneration after seed tree cutting. U.S. Forest Service Research Paper SO-123, (city & state).

_____ and _____. 1983. Regeneration in small and large sawtimber sweetgum-red oak stands following selection and seed tree harvest: 23-year results. Southern Journal of Applied Forestry 7:176-184.

_____ and _____. 1988. Growth and development of two sweetgum-red oak stands from origin through 29 years. Southern Journal of Applied Forestry 12:73-78.

Kelty, M. J. 1992. Comparative productivity of monocultures and mixed-species stands. Pages 125-141 *in* M. J. Kelty, B. C. Larson and C. D. Oliver, editors, The ecology and silviculture of mixed-species forests. Kluwer Academic Publishers, Boston, MA.

_____, E. M. Gould Jr. and M. J. Twery. 1987. Effects of understory removal in hardwood stands. Northern Journal of Applied Forestry 4:162-164.

Kittredge, D. B. 1986. The effect of stand structure on the growth of red oaks in mixed hardwood stands. Dissertation, Yale University, New Haven, CT.

_____. 1988. The influence of species composition on the growth of individual red oaks in mixed stands in southern New England. Canadian Journal of Forest Research 18:1550-1555.

Lockhart, B. R., A. W. Ezell, J. D. Hodges and W. K. Clatterbuck. 2000. Seventeen-year development of a mixed cherrybark oak-sweetgum plantation planted at different spacings in east-central Mississippi. Proceedings of the tenth biennial southern silvicultural research conference. U.S. Forest Service General Technical Report SRS-in press, (city & state).

Meadows, J. S. 1993. Logging damage to residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi delta. Pages 248-260 *in* A. R. Gillespie, G. R. Parker, P. E. Pope and G. Rink, editors, Proceedings of the ninth central hardwood forest conference. U.S. Forest Service General Technical Report NC-161, (city & state).

_____. 1995. Epicormic branches and lumber grade of bottomland oak. Pages 19-25 *in* G. Lowery and D. Meyer, editors. Advances in hardwood utilization: following profitability from the woods through rough dimension, proceedings of the twenty-third annual hardwood symposium. National Hardwood Lumber Association, Memphis, TN.

_____. 1996. Thinning guidelines for southern bottomland hardwood forests. Pages. 98-101 *in* K. M. Flynn editor, Proceedings of the southern forested wetlands ecology and management conference, Consortium for Research on Southern Forested Wetlands, Clemson University, Clemson, SC.

Moser, W. K. 1994. Interspecific and intertemporal differences in carbon uptake and allocation as evidence of the competitive ability of northern red oak (*Quercus rubra* L.). Dissertation, Yale University, New Haven, CT.

O'Hara, K. L. 1986. Developmental patterns of residual oaks and yellow-poplar regeneration after release in upland hardwood stands. Southern Journal of Applied Forestry 10:244-248.

Oliver, C. D. 1976. The development of northern red oak in mixed stands in central New England. Yale School of Forestry and Environmental Studies Bulletin No. 91, New Haven, Connecticut, USA.

Oliver, C. D. 1982. Stand development-its uses and methods of study. Pages 100-112 *in* J. E. Means, editor, Forest succession and stand development research in the Northwest, Forest Research Laboratory, Oregon State University, Corvallis.

Oliver, C. D. and B. C. Larson. 1996. Forest stand dynamics. John Wiley & Sons, New York.

Putnam, J. A., G. M. Furnival and J. S. McKnight, 1960. Management and inventory of southern hardwoods. U.S. Forest Service Agricultural Handbook No. 181, Washington, DC.

Smith, D. M., B. C. Larson, M. J. Kelty and P. M. S. Ashton. 1997. The practice of silviculture: applied forest ecology. John Wiley & Sons, New York.

Stubbs, J. 1986. Hardwood epicormic branching - small knots but large losses. Southern Journal of Applied Forestry 10:217-220.

Young, N. L. 1980. Phenology of plantation grown cherrybark oak, yellow-poplar, and sweetgum. MS Thesis, Louisiana State University, Baton Rouge.

ECOLOGY AND MANAGEMENT OF BOTTOMLAND HARDWOOD SYSTEMS:

The State of Our Understanding

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A Phytosociological Description of a Remnant Bottomland Hardwood Forest in Denton, Texas

LLELA Research Note 5
June 2003

This *Note* is a corrected version of the essay that appeared in the November 1999 issue of the *Texas Journal of Science* (Vol 51(4):309-316). Although it does not describe a site at LLELA, it is important for regional comparisons and forest restoration work, which is why it is included as a *LLELA Research Note*. The raw data is also available for research or study on the LLELA website.

A Phytosociological Description of a Remnant Bottomland Hardwood Forest in Denton, Texas

by *Dwight Barry and Andrew J. Kroll,*
University of North Texas

ABSTRACT

A remnant bottomland hardwood forest near Denton, Texas, was surveyed in order to describe its phytosociological composition. Hackberry, cedar elm, and green ash dominate the site with respect to basal area, density, and frequency in the forest. Importance values for these three dominant species are 33%, 27%, and 11%, respectively. Cluster analyses of plot metrics indicate a patchy forest. Many trees were found to be well over 200 years old, indicating that the forest predates any significant Anglo settlement. These results indicate that the forest may be classified as transitional old-growth of the hackberry-elm-ash forest type. Because of its unique status as a relatively intact north Texas bottomland hardwood forest, the data obtained from this site can be used for comparisons with other bottomland forests, and as a guideline for future restoration efforts throughout the northwestern region of the southern bottomland forests.

INTRODUCTION

The bottomland hardwood ecosystem in Texas prior to European settlement once extended over 6.5 million hectares; it is estimated that less than 40% of this original extent still remains (Frye 1986), with only a few small and isolated patches of old growth scattered amongst the floodplains of the eastern third of the state. Intact bottomland hardwood forests are among the list of endangered ecosystems in the United States; in the past 50 years, losses of these forest have at times been greater than 120,000 ha per year (MacDonald et al. 1979, as cited in King 1996). This survey was undertaken in order to analyze and classify a remnant bottomland forest, the results of which can be used to assist future ecological management and restoration of these disappearing ecosystems (Shear et al. 1996; Michener 1997).

SITE LOCATION

The site is a bottomland hardwood forest of approximately 93 ha, lying within the Cross Timbers and Prairies physiogeographic province of north-central Texas. The forest is located at UTM coordinates 682045 W and 3684420 N (Zone 14), along the banks of the Elm Fork of the Trinity River approximately 10 km northeast of downtown Denton in Denton County. It is located within the Lewisville Lake Wildlife Restoration Area, which is owned and managed by the U.S. Army Corps of Engineers.

The forest lies on the Elm Fork's floodplain. The site is covered by a layer of silty clay loam, classified by the USDA as Ovan clay, a soil type most often found on the floodplains of major regional streams (Ford & Pauls 1980). This series resides within the family of fine, montmorillonitic, thermic Udic Chromusterts soils. Both the permeability and the surface runoff of the soil are reported as slow (Ford & Pauls 1980).

METHODS

A grid of 128 100 m^2 circular plots was laid out and sampled using standard forestry metrics, including diameter at breast height (dbh), density, and frequency of occurrence. At total of 972 trees were sampled within the plot areas.

For determination of age, 24 individuals of hackberry, 13 individuals of green ash, and 4 individuals of bur oak through all size classes were randomly selected for increment boring. After obtaining the dbh of each tree, a 16 inch increment borer with a 0.2 inch diameter was drilled into the tree at breast height to obtain a core sample. The rings on each core sample were double counted in the field. The cores were then replaced in the hole and covered with a dab of mud to prevent insect or fungal intrusion into the tree's bole.

Phytosociological importance values for each species were calculated for the forest through an averaging of relative dominance (basal area per unit area sampled), density, and frequency of occurrence values. Linear regression was performed on age class and dbh data for the three species chosen for age class analysis. Regression was tested at an ? =0.05, and descriptive statistics were also generated in order to obtain 95% confidence limits. Cluster analyses were used to determine the relative similarity of the individual plots. K-Means clustering was used for specified cluster designation, the complete linkage joining algorithm was used in order to maximize differences between plot distance values, percent disagreement distance algorithm was used for categorical (presence/absence) data, and City-block distance algorithm was used for continuous data in order to minimize the effects of extreme values.

RESULTS

This forest contains at least 24 different tree species, the most common of which include sugar hackberry (*Celtis laevigata*), green ash (*Fraxinus pennsylvanica*), eastern cottonwood (*Populus deltoides*), bur oak (*Quercus macrocarpa*), American elm (*Ulmus americana*), cedar elm (*Ulmus crassifolia*), and slippery elm (*Ulmus rubra*). In the understory, common trees include hawthorn (*Crataegus* spp.), box elder (*Acer negundo*), Eve's necklace (*Sophora affinis*), and bois d'arc (*Maclura pomifera*). Table 1 lists all tree species encountered in the forest.

Table 2 gives the importance values of each tree species found within sampling plots. Hackberry and cedar elm dominate this forest with respect to basal area, density, and frequency in the forest; hackberry had an importance value of 32.55%, while cedar elm had an importance value of 26.63%. Green ash had an importance value of 11%. Table 3 gives the total basal area, number of trees per hectare, and frequency of plot occurrence for each tree species. Snag density was found to be 57 standing dead trees per hectare. These results indicate that the forest may be classified as a hackberry-elm-ash forest type (Nixon 1986).

The regression analysis for the age to dbh relationship demonstrated a positive linear relationship between age and size for hackberry and green ash. For hackberry, $y = 1.7015x + 7.4975$ ($R2 = 0.68$, $p<0.0001$); for green ash, $y = 1.0175x + 14.597$ ($R2 = 0.7088$, $p=0.0003$). The small sample size for bur oak prevented the use of linear regression; estimates were derived instead using an average ring-to-diameter ratio of 2.3 years per cm of diameter. Allometric formulae for these species are summarized in Table 4.

Cluster analysis of the presence and absence of the different tree species by plot and the analysis of plot metrics demonstrated that the forest is highly patchy in terms of both species composition and association. At the 50% relative dissimilarity level, there were 14 different classification clusters, indicating that plot species composition varies extensively across the sampled areas. Many spatially adjacent plots were not clustered together in the results of 5 category K-Means clustering, further demonstrating the patchy distribution of the forest's tree species. The highly patchy nature of this forest is a classic characteristic of natural mature and old growth forests, especially on floodplains.

DISCUSSION

The results of our analysis indicate that the forest is dominated by hackberry, cedar elm, and green ash, and is likely to remain so well into the future. These three species are able to tolerate relatively prolonged periods of inundation and are shade tolerant, attributes that have helped them survive and propagate in the closed canopy and in the frequently flooded environment beside the Elm Fork. Hackberry and cedar elm occurred throughout most of the size classes (except for the very large ones); this evidence of recruitment indicates that these species are replacing themselves and remaining as the "climax" community. The extreme size (and likely old age) of many individual trees within the forest indicates that conditions for their growth have existed for at least 150-250 years; the forest itself could be many centuries older.

The presence of numerous oak, pecan, and black walnut seedlings, paired with the sizable amount of mature bur and Shumard oaks located in the forest, may indicate a maturation of the floodplain soils underlying the forest, a condition that might lead to the oak-hickory community that is often found in old growth bottomland hardwood stands. The hypothetical movement of this forest to such a community is an event that would occur over hundreds of years and be subject to several factors including extent and duration of hydroperiods (flooding, rain, etc.). The presence of Lake Ray Roberts upstream will eliminate many of the flood cycles that have contributed so much to the current structure of the site; without the flood events which were so common, the water table underlying the forest should stabilize. Indication that this is already happening comes from the black walnuts, which are found in drier soils than hackberry, cedar elm, and green ash. The current distribution of bur oak, with large trees located on drier river-front sites and numerous seedlings readily apparent throughout the forest, also points to a changing water table, as bur oaks cannot withstand prolonged periods of inundation. Without the competitive advantage provided by past flood events, the aspect of this forest may change from a hackberry/elm/ash forest to one dominated by a combination of bur and Shumard oaks and black walnuts, which are representative of classic old-growth and late successional bottomland hardwood forests (Hodges 1997).

The results of the cluster analysis indicate a forest with a patchy distribution. Respective tree species tend to occur in clumped distributions; this is likely a result of seed dispersion and the site’s topography. Because of the forest’s general lack of vertical relief, elevation changes of 0.25-0.5 m may drastically alter the species present at that location. Lower areas are more inclined to support forested wetlands or maintain soil inundation for longer periods of time, thus affecting the size and species of trees present. In addition, the understory vegetation present at various sites is heavily reliant upon the level of soil moisture and inundation.

These findings are consistent with trends in bottomland forest ecology and succession as noted by Nixon (1986), Nixon et al. (1990), Hodges (1997), and Kellison & Young (1997). Based on descriptive forest classification systems, we have determined that the forest as a whole may be classified as transitional old-growth (Oliver & Larson 1990). Several smaller stands within this forest may be classified as true old-growth, based on species composition, age/size classes, and stand structural features. Because of its unique status as a relatively intact North Texas bottomland hardwood forest, the forest can be used as a baseline for comparisons with other similar forests in the area.

ACKNOWLEDGMENTS

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LITERATURE CITED

Ford, A., & E. Pauls. 1980. Soil survey of Denton County, Texas. United States Department of Agriculture, Soil Conservation Service. 160 pp.

Frye, R. G. 1986. Current supply, status, habitat quality, and future impacts. Pp. 24-28, *in* Bottomland hardwoods in Texas (C. A. McMahan & R. G. Frye, eds.), Proceedings of an Interagency Workshop on Status and Ecology, 6-7 May, 1986, Nacogdoches, TX, Texas Parks and Wildlife Department, Publication # PWD-RP-7100-133-3/87, Austin, TX, 170 pp.

Hodges, J. D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management 90:117-125.

Kellison, R. C., & M. J. Young. 1997. The bottomland hardwood forest of the southern United States. Forest Ecology and Management 90:101-115.

King, S. L. 1996. The effects of flooding on bottomland hardwood seedlings planted in lignite mine spoil in east Texas. Texas Journal of Science, 48(1):75-84.

Michener, W. K. 1997. Quantitatively evaluating restoration experiments: research design, statistical analysis, and data management considerations. Restoration Ecology 5(4):324-337.

Nixon, E. S. 1986. Bottomland community structure in east Texas. Pp. 8-19, *in* Bottomland hardwoods in Texas (C. A. McMahan & R. G. Frye, eds.), Proceedings of an Interagency Workshop on Status and Ecology, 6-7 May, 1986, Nacogdoches, TX, Texas Parks and Wildlife Department, Publication # PWD-RP-7100-133-3/87, Austin, TX, 170 pp.

Nixon, E. S., G. A. Sullivan, S. D. Jones, G. D. Jones, and J. K. Sullivan. 1990. Species diversity of woody vegetation in the Trinity River Basin, Texas. Castanea 55(2):97-105.

Oliver, C. D. & B. C. Larson. 1990. Forest stand dynamics. MacGraw-Hill, New York, 467 pp.

Shear, T. H., T. J. Lent, & S. Fraver. 1996. Comparison of restored and mature bottomland hardwood forests of southwestern Kentucky. Restoration Ecology 4(2):111-123.

Table 1. Tree and large shrub species encountered in the relict bottomland forest.

Species	**Common Name**
Acer negundo	Box elder
Broussonetia papyrifera	Paper mulberry
Bumelia lanuginosa	Chittamwood
Carya illinoensis	Pecan
Celtis laevigata	Hackberry
Cornus drummondii	Rough-leaf dogwood
Crataegus spp.	Hawthorn
Diospytos virginiana	Common persimmon
Fraxinus pennsylvanica	Green ash
Gleditsia triacanthos	Honey locust
Juglans nigra	Black walnut
Juniperus virginiana	Eastern red cedar
Maclura pomifera	Bois d'arc
Morus rubra	Red mulberry
Platanus occidentalis	American sycamore
Populus deltoides	Eastern cottonwood
Quercus macrocarpa	Bur oak
Quercus shumardii	Shumard oak
Salix nigra	Black willow
Sophora affinis	Eve's necklace
Ulmus alata	Winged elm
Ulmus americana	American elm
Ulmus crassifolia	Cedar elm
Ulmus rubra	Slippery elm

Table 2. Importance values of sampled tree species.

Species	**Common Name**	**Relative Dominance**	**Relative Density**	**Relative Frequency**	**Importance Value**
Celtis laevigata	Hackberry	30.50	39.92	27.25	32.55
Ulmus crassifolia	Cedar elm	34.28	23.46	22.14	26.63
Fraxinus pennsylvanica	Green ash	8.68	12.14	12.17	11.00
Snags		5.19	7.51	12.65	8.45
Quercus macrocarpa	Bur oak	14.89	2.37	5.35	7.54
Maclura pomifera	Bois d'arc	2.06	2.26	3.65	2.66
Bumelia lanuginosa	Chittamwood	1.74	1.95	4.14	2.61
Juglans nigra	Black walnut	0.43	2.67	3.65	2.25
Crataegus spp.	Hawthorn	0.42	2.47	2.43	1.77
Carya illinoensis	Pecan	0.25	1.54	1.95	1.25
Acer negundo	Box elder	0.26	1.44	0.73	0.81
Morus rubra	Red mulberry	0.09	0.72	1.46	0.76
Quercus shumardii	Shumard oak	1.04	0.31	0.49	0.61
Sophora affinis	Eve's necklace	0.05	0.51	0.73	0.43
Ulmus americana	American elm	0.09	0.41	0.49	0.33
Broussonetia papyrifera	Paper mulberry	0.02	0.11	0.24	0.12
Gleditsia triacanthos	Honey locust	0.01	0.11	0.24	0.12
Ulmus rubra	Slippery elm	0.00	0.10	0.24	0.11
Sum		**100**	**100**	**100**	**100**

Table 3. Summary results of forest composition survey based on plot analysis.

Species	**Common Name**	**Dominance (m^2/ha)**	**Density (stems/ha)**	**Frequency (# of plots)***
Celtis laevigata	Hackberry	10.34	303	112
Ulmus crassifolia	Cedar elm	11.62	178	91
Fraxinus pennsylvanica	Green ash	2.94	92	50
Snags		1.76	57	52
Quercus macrocarpa	Bur oak	5.05	18	22
Maclura pomifera	Bois d'arc	0.70	17	15
Bumelia lanuginosa	Chittamwood	0.59	15	17
Juglans nigra	Black walnut	0.14	20	15
Crataegus spp.	Hawthorn	0.14	19	10
Carya illinoensis	Pecan	0.08	12	8
Acer negundo	Box elder	0.09	11	3
Morus rubra	Red mulberry	0.03	5	6
Quercus shumardii	Shumard oak	0.35	2	2
Sophora affinis	Eve's necklace	0.02	4	3
Ulmus americana	American elm	0.03	3	2
Broussonetia papyrifera	Paper mulberry	0.00	1	1
Gleditsia triacanthos	Honey locust	0.00	1	1
Ulmus rubra	Slippery elm	0.00	1	1
Sum		33.89	759	411

* total number of plots = 128

Table 4. Age estimation formulae for hackberry, green ash, and bur oak derived through regression analysis of dbh and age information. +/- indicates 95% confidence limits.

Species	**Formula to estimate age**	**95% confidence limits**
Celtis laevigata	age = (1.7015*dbh) + 7.4975	+/- 0.03*dbh
Fraxinus pennsylvanica	age = (1.0175*dbh) + 14.597	+/- 0.23*dbh
Quercus macrocarpa	age = 2.3*dbh	+/- 0.38*dbh

Great Trinity Forest Management Plan

HARDWOOD SILVICULTURE

An Examination of the Riparian Bottomland Forest in North Central Texas Through Ecology, History, Field Study, and Computer Simulation

(Thesis of Sheralyn S. Holcomb, BA for the Degree of Master of Science, University of North Texas, August 2001)

AN EXAMINATION OF THE RIPARIAN BOTTOMLAND FOREST IN NORTH CENTRAL TEXAS THROUGH ECOLOGY, HISTORY, FIELD STUDY, AND COMPUTER SIMULATION

Sheralyn S. Holcomb, B.A.

Thesis Prepared for the Degree of

MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

August, 2001

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Holcomb, Sheralyn S. An examination of the riparian bottomland forest in north central Texas through ecology, history, field study, and computer simulation. Master of Science (Environmental Science), August 2001. 108 pp., 13 tables, 13 figures, references, 158 titles.

This paper explores the characterization of a riparian bottomland forest in north central Texas in two ways: field study, and computer simulation with the model ZELIG. First, context is provided in Chapter One with a brief description of a southern bottomland forest, the ecological services it provides, and a history of bottomland forests in Texas from the nineteenth century to the present. A report on a characterization study of the Lake Ray Roberts Greenbelt forest comprises Chapter Two. The final chapter reviews a phytosocial study of a remnant bottomland forest within the Greenbelt. Details of the ZELIG calibration process follow, with a discussion of ways to improve ZELIG's simulation of bottomland forests.

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INTRODUCTION

Bottomland hardwood forests are valuable ecosystems that are disappearing rapidly in Texas. Impoundments, development, and timber harvesting are among the factors contributing to this decline. In addition to providing habitat for a variety of wildlife, they perform necessary ecological functions such as flood control, erosion control, and sequestration of sediments and chemical pollutants (Kellison and Young, 1997). Approximately twenty percent of these forests have been lost in the southern states since 1950 (Kellison and Young, 1997); by 1986, over one-half million acres had been inundated by reservoirs in Texas (McMahan, 1986). Thus it has become increasingly important to protect and to manage carefully the remaining bottomland forests, so that they may continue to perform the biological functions necessary for a healthy watershed.

This paper explores the process of characterizing a riparian bottomland forest in north central Texas in two different ways: by field study, and by computer simulation with the forest gap model ZELIG. First, however, context is provided in Chapter One with a brief description of a typical southern bottomland hardwood forest, and what ecological services this type of ecosystem provides. Chapter One also includes an overview of historic losses of bottomlands and forest conservation efforts in Texas from the late nineteenth century to the present. A report on a characterization study of the Lake Ray Roberts Greenbelt forest makes up the second chapter. The final chapter begins with a review of a detailed phytosocial forest study of a remnant bottomland forest within the Greenbelt. Details of the ZELIG model calibration process follow, and the chapter concludes with a discussion of possible ways to improve the model's performance in bottomland hardwood forests. If the Greenbelt forest can be modeled with a reasonable degree of accuracy, it may be possible in the future to use the model to simulate different management and restoration techniques, in order to judge their potential to achieve a mature forest resembling the remnant forest modeled for this study.

The objectives of this paper are

1. to provide justification of the preservation and restoration of bottomland hardwood forests in north central Texas by reviewing their ecology, ecological benefits, and history of use and abuse in Texas;
2. to characterize the Lake Ray Roberts Greenbelt corridor with regard to its potential value for a particular ecological benefit (wildlife habitat)
3. to calibrate the ZELIG forest simulation model for bottomland hardwood forests in north central Texas using field data from the Lake Ray Roberts Greenbelt.

CHAPTER 1

BOTTOMLAND HARDWOOD FORESTS IN ECOLOGICAL AND HISTORICAL CONTEXT

The Ecology of Bottomland Hardwood Forests

In 1989, the U.S. Army Corps of Engineers (COE), the Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS), and the Soil Conservation Service (SCS) expanded their wetland definition criteria to include bottomland hardwood forests (Kellison and Young, 1997). However, this expansion resulted in a storm of controversy and revision of wetland designation criteria, demonstrating that the political ramifications of scientific definitions of wetlands, including bottomland hardwood forests, can be extensive and unpleasant. This section of this paper is a brief description of bottomland forests based upon documented distinguishing features.

Although no exact rules exist for defining any ecosystem, bottomland hardwood forests possess several distinguishing characteristics that enable them to be differentiated from other types of systems. One such characteristic is their location; according to Hodges (1997), "bottomland hardwoods occur primarily on alluvial floodplain sites, although other non-alluvial wet sites also support many of the same hardwood species." Periodic inundation or soil saturation is typical of these forest sites. A hydrological regime such as this supports mixed hardwood and, in the southern United States, hardwood-cypress forests (Gower et al., 1997). Topography and hydrology in turn affect the soil origin and composition, which gives the forests another of their major distinguishing features (Hodges, 1997).

The topography of major southern stream valleys includes a current floodplain and a series of terraces formed from older floodplains (Wharton et al., 1982). Forests in the floodplain and youngest terrace are most subject to flooding and the accompanying sediment deposition, and so they tend to be the most productive (Hodges, 1997). The geomorphological profile of these areas is characterized by a series of small ridges, flats, and sloughs, which influence water retention, sediment deposition, and soil texture (Hodges, 1997). Species composition also varies with the topography as one proceeds along a trajectory moving away from the river. A typical major stream bottom in the southern United States may have willows and cottonwoods on the riverbanks; less water tolerant species (e.g. elm, pecan, and sugarberry) growing on the ridges; water-loving species (e.g. water hickory and overcup oak) in the sloughs; and mixtures of both types, as well as median species (e.g. green ash) on the flats (Hodges, 1997). Table 1 lists topographical features of a major southern bottomland forest, along with some of the species associations found on them.

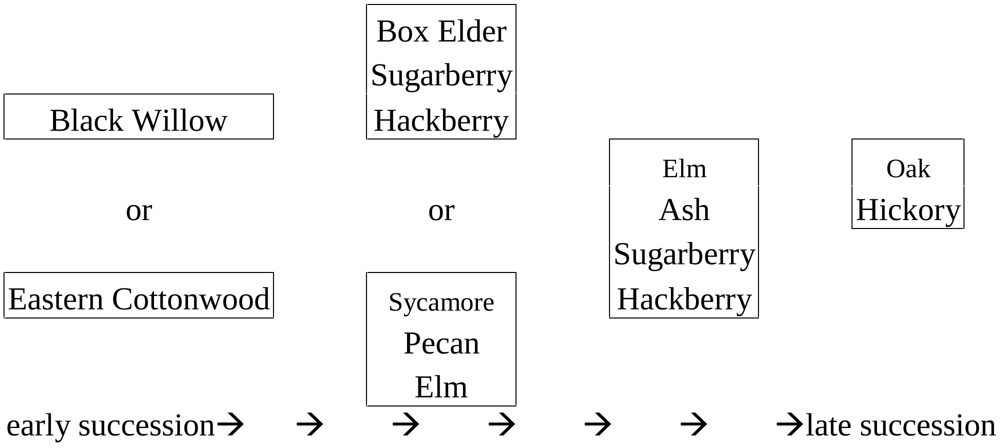
Succession of species in major southern stream bottoms follows one of two general patterns, depending upon whether the site is well or poorly drained; rate of sediment deposition also affects the pattern of species succession (Hodges, 1997). Figure 1 shows the general order of succession on major southern bottomlands, with regard to the species found in the Ray Roberts Greenbelt bottomland. The most pristine remnant bottomland hardwood stand in the Greenbelt is dominated by the elm-hackberry-ash

Table 1. Topographical Features and Examples of Corresponding Species Associations Found in Major Southern River Bottoms

Topographical feature	Species Composition
Bar	Willow, Cottonwood
Front	Elm, Sycamore, Pecan, Sugarberry
Flat	Nutall Oak, Green Ash, Sugarberry, Elm, Red Maple
Slough	Willow, Overcup Oak, Water Hickory
Ridge	Sweetgum, Water Oak, Willow Oak, Green Ash
Flat	Overcup Oak, Water Hickory
Swamp	Baldcypress, Water Tupelo
Ridge	Sweetgum, Hickory, Red Oak, Swamp Chestnut Oak, Winged Elm, Blackgum
Flat	Sweetgum, Water Oak, Willow Oak, Green Ash, Nuttall Oak
Slough	Overcup Oak, Water Hickory

(adapted from Hodges, 1997)

association, with some cottonwood, oak, and other species. See Table 2 for a list of species in this remnant. Other areas along the Elm Fork contain black willow, pecan, and sycamore, but the hackberry/elm/ash association remains the dominant one (Barry et al., 1999). As one progresses up the terraces to higher ground, the forest composition shades into upland species.



(adapted from Hodges, 1997)

Figure 1. Ray Roberts Greenbelt tree species associations, in order of general successional pattern.

Table 2. Tree Species from the Remnant Bottomland Forest on the Ray Roberts Greenbelt

Common Name	**Scientific Name**
Box Elder	*Acer negundo*
Chittamwood	*Bumelia lanuginosa*
Pecan	*Carya illinoensis*
Sugar Hackberry	*Celtis laevigata*
American Hackberry	*Celtis occidentalis*
Rough-leaf Dogwood	*Cornus drummondii*
Hawthorn	*Crataegus* spp.
Common Persimmon	*Diospytos virginiana*
Green Ash	*Fraxinus pennsylvanica*
Honey Locust	*Gleditsia triacanthos*
Black Walnut	*Juglans nigra*
Eastern Red Cedar	*Juniperus virginiana*
Bois d'arc	*Maclura pomifera*
Red Mulberry	*Morus rubra*
American Sycamore	*Platanus occidentalis*
Eastern Cottonwood	*Populus deltoides*
Bur Oak	*Quercus macrocarpa*
Shumard Oak	*Quercus shumardii*
Black Willow	*Salix nigra*
Eve's Necklace	*Sophora affinis*
Winged Elm	*Ulmus alata*
American Elm	*Ulmus americana*
Cedar Elm	*Ulmus crassifolia*
Slippery Elm	*Ulmus rubra*

(from Barry and Kroll, 1999)

Ecological Services Performed by Bottomland Hardwood Forests

The ecological role of the bottomland hardwood forest has only recently begun to be acknowledged. Historically, this productive ecosystem was perceived to be more valuable as farmland, but that perception is changing (Kellison and Young, 1997). Now, the bottomland forest is known to provide many crucial ecological services. Perhaps the most obvious and best documented is that of wildlife habitat. In addition to the resident bird population, bottomland forests, particularly in riparian areas, host a wide variety of migratory waterfowl (Kellison and Young, 1997). Many animal species, both game and non-game, also use these areas as homes and as corridors between habitats (Mathew, 1992, cited in Kellison and Young, 1997). In fact, the diversity of plant and animal species found in these forests is a subtropical echo of the richness of the tropical rainforests, and is nearly unrivalled in the lower 48 United States (Kellison and Young, 1997).

Wildlife habitat is only one of many benefits of intact bottomland forest ecosystems. Another is flood and erosion control (Maxwell and Martin, 1970; Clark and Benforado, 1981). The natural topography of riparian bottomlands includes sloughs and basins that fill and hold water during a flood event, reducing the magnitude of flooding downstream (Kellison and Young, 1997). Water retention also facilitates the recharge of aquifers (Maxwell and Martin, 1970; USFWS, 1985). Moreover, the thick vegetation found in these ecosystems anchors soil, thus reducing the scouring effects of rapid water movement that lead to erosion (Wharton, 1980). A benefit of the water-retention service of bottomland hardwoods is improved downstream water quality (Kellison and Young, 1997). By holding floodwaters in their sloughs and basins, riparian forests sequester sediments that would otherwise flow into the stream channel and increase the stream's turbidity. Moreover, riparian hardwood systems contain soils with predominately clay-sized particles, which are able to attract and bind a number of chemical pollutants, including pesticides (Dickson, 1986). They also hold "radioactive cesium, oil, nitrogen, sewage, and fly ash" (Dickson, 1986). Thus, bottomland forests shield precious water resources from damage by anthropogenic contaminants (Odum, 1978; in Dickson, 1986).

Another ecological function related to the water-retention capabilities of bottomland systems is nutrient cycling (Kellison and Young, 1997). As sediments are deposited in the backwater areas, nutrients are sequestered and released gradually into the stream over time (Chabreck, 1986). This process stabilizes the amount of nitrogen and other nutrients that reach the stream channel, preventing eutrophication of downstream systems. Eutrophication and increased turbidity, both of which are associated with alterations of riparian hydrology, are potentially devastating to estuarine systems, because they lead to lower dissolved oxygen levels (Chabreck, 1986). Bottomland systems also regulate and maintain an appropriate salinity gradient in estuaries. Removal of the forests results in a wide fluctuation of salinity levels from very low during flooding events to very high during periods of low water flow (Chabreck, 1986). Because fish and wildlife are not adapted to such wide variations in salinity, estuarine productivity declines when bottomland forests are destroyed. The Gulf Coast region supports the most productive fisheries, maintains the highest harvest of fur-bearing animals, and supports the largest populations of migratory birds in the United States (Chabreck, 1986). All of these are dependent on the estuaries of the Gulf Coast, which must maintain normal salinity gradients to remain productive. Thus, the disappearance of bottomland hardwood forests can be devastating to downstream estuaries as well as the watersheds in which they are located.

Discussions of the ecological benefits provided by any ecosystem raise the question of how to value these benefits in economic terms. Ecosystem benefits can be divided into two categories: goods, which includes timber and other commodities actually harvested from the forest and sold, and services, which include "environmental functions that produce benefit flows over time," such as those mentioned in the foregoing section (Aylward and Barbier, 1992). Traditionally, only the goods that could be extracted from an ecosystem have been considered in any economic appraisal. In recent decades, however, attempts have been made to evaluate ecosystems in terms of what the services they provide would cost if society had to undertake the performance of the same services (Costanza et al., 1997). Although a full discussion of this topic is beyond the scope of this paper, a brief introduction is included here, in order to provide further justification for the effort expended upon study, restoration, and preservation of these ecosystems.

Barde and Pearce (1991) and Aylward and Barbier (1992) list four different values that can be attached to ecosystems:

1. use value, which represents the actual uses (e.g. recreational) made of the area, as well as the goods extracted from it;
2. indirect value, which is the services provided by the intact ecosystem;
3. option value, which refers to the potential future value of the area; and
4. existence value, which is the value of the ecosystem for people who wish it to remain intact but do not intend to use it directly.

Moreover, ecological diversity may greatly impact the value of the goods and services an ecosystem provides, and should be considered in any economic valuation of that ecosystem, (Aylward and Barbier, 1992). Since bottomland hardwood forests are highly diverse systems, this last point is particularly applicable to them. Another consideration to be made is how a change, either qualitative or quantitative, in an ecosystem’s services can change the value of the goods harvested from that ecosystem (Costanza et al., 1997). Thus, the different levels of use are linked, which further complicates the issue of how to value ecosystems in economic terms. Given that bottomland forests provide so many essential services, preserving them is in the interests of people as well as the wildlife that call these forests home.

A History of Bottomland Hardwood Forests in Texas

It is clear that significant amounts of bottomland hardwood forests have been lost nationally and in Texas since the time of European settlement, although the extent of the loss is impossible to quantify precisely. Dahl and Johnson (1991, cited in Kellison and Young, 1997) estimate that total wetland loss in the lower forty-eight states from pre-colonial times to 1985 is 48.1 million of the original 89.5 million hectares (118.9 million and 221.2 million ac, respectively). More specifically, bottomland hardwood forests in the Mississippi Delta region had been reduced from a pre-colonial level of 25 million acres (10.1 million ha) to 4.5 million ac (1.8 million ha) by the mid-1980's, according to Dickson (1986). Kellison and Young (1997) estimate the losses differently. Measuring productive bottomland forests, i.e. forests capable of producing at least 1.4 m^3/ha/yr of saleable timber, they estimate the pre-colonial extent in the South to be more than 16 million ha (39.54 ac). After reaching a historic low in the late nineteenth century, the forests had recovered somewhat by the 1950's, only to drop again to 12,223 million ha (30,203 ac) in 1985 (Kellison and Young, 1997). In 1985, non-industrial, private landowners were found to own approximately 69% of bottomland forests in the South, but they were responsible for 92% of the loss of these systems between 1952 and 1985

(Kellison and Young, 1997). Table 3 contains ownership and loss estimates in the South for this thirty-three year period.

Table 3. Percentage of Distribution and Loss of Bottomland Forests in the South

Forest Management Type	National forest	Other public ownership	Forest industry	Non-industrial private ownership
% Relative distribution in 1985	1.5	6	23.7	68.8
% Loss of forest area 1952-1985	4		4	92

(adapted from Kellison and Young, 1997)

In Texas, 1.8 million ac (730,000 ha) of bottomland forests were present in 1976 (USFWS, 1985; Lay, 1986). Of this amount, over 700,00 ac (283,290 ha) was rated "poorly stocked" and needing regeneration; 46,100 ac (18,656.67 ha) was rated "medium stocked" (USFWS, 1985; Lay, 1986). The 1.8 million ac was calculated to be an eighteen percent loss from 1935 acreage, with 660,000 ac having been lost to impoundments alone in the twentieth century (USFWS, 1985; Lay, 1986). North central Texas has lost 5767 ac (2333.9 ha) in the past twenty years to the impoundment of Lake Ray Roberts (IAS, 1988; 1999). Approximately 500 ha (1235.5 ac) of bottomland forest located in the Ray Roberts Greenbelt (Barry et al., 1999) are threatened with damage due to altered hydrological regimes. While these figures are merely estimates, and often do not precisely agree, they show dramatic losses to bottomland hardwood forests since European colonization.

The history of the use of bottomland hardwood forests in Texas can be divided into three different, although not altogether distinct, time periods. These could be thought of as the period prior to European settlement, a period of exploitation, and a period of misuse tempered somewhat by conservation efforts. Lay (1986) demarcates these periods as pre-1820, 1820-1920, and 1920-1970, respectively. Prior to 1820, "a full complement of plants and animals was present to fill all ecological niches. Diversity was at its peak because all stages of plant succession were present.... It was not a perfect stand of large trees. All kinds and ages were present, including dead and dying" (Lay, 1986). In addition to species found in bottomland forests today, one could see animals such as Carolina parakeets, passenger pigeons, black bears, and red wolves, which are now completely or locally extinct. Native Americans used the ecotone between the bottomland and upland forests as camping sites, in order to have easy access to the rich hunting (Lay, 1986). While one should avoid the temptation to view this period as overly idyllic, it is certainly clear that human impact had not yet disrupted the ecological functions of the ecosystem.

This began to change with the arrival of European settlers. During the period from 1820 to 1920, the forests were overgrazed, overhunted, overharvested, and cleared for agriculture (Lay, 1986). No effort was made to conserve the resources, or even to use them efficiently. Timber harvesting all over the state increased exponentially after the Civil War, as mill owners established ever larger empires; by 1880 many individual owners controlled over 100,000 acres of forestland each (Maxwell and Martin, 1970). Logging practices were wasteful and inefficient, as both machinery and skidders carrying cut trees knocked down smaller trees that had escaped cutting (Maxwell and Martin, 1970). As a result, resources were exhausted, and by 1920 timber production had dropped almost to the post-Civil War level. Indeed, for the majority of Texas forests, "from virgin forest to cutover wasteland had taken only twenty-five years" (Maxwell and Martin, 1970). Despite the specter of dwindling forest resources and the young but growing conservation movement in both the United States and Texas, exploitation continued into the twentieth century.

Some of the continued exploitation of bottomland forests arose out of the necessity of the Great Depression. As people made temporary homes along rivers, riparian forests were hunted so heavily that even common animals such as deer became scarce (Lay, 1986). Timber companies scoured the forests for the last virgin stands and merchantable second growth. Harvesting practices remained inefficient, and ecologically unsound techniques such as highgrading (cutting all trees above a certain diameter) were ubiquitous (Lay, 1986). Additionally, in east Texas, hardwood and mixed hardwood-pine forests were being converted to pure pine stands as result of "an all-out propaganda and subsidy war on hardwoods" (Lay, 1986). The building of reservoirs has inundated more than one-half million acres of bottomland forests statewide since 1920, and much of the remaining stands have been adversely affected by the changes in hydrology resulting from those projects (McMahan, 1986). Other human activities of this period that have destroyed or damaged hardwood forests include recreation, urbanization, and pollution (Dickson, 1986). Thus, the history of bottomland hardwood forests in Texas since 1820 has been one of misuse and exploitation. However, since approximately the turn of the century efforts have begun to reverse this bleak trend. What follows is a history of policies enacted with the intent of preserving these valuable ecosystems.

The History of Forest Preservation Policy in Texas

Although the foregoing section presents a bleak picture of the fate of bottomland hardwoods in Texas, in the period between 1820 and 1970, the situation was not entirely hopeless. During the twentieth century, despite wasteful harvesting practices and losses due to other anthropogenic factors, some recovery of the forests did occur. Reductions in grazing, easing of suppression of hardwood species, and reintroduction of animals such as otters and beavers contributed to the partial recovery (Lay, 1986). Perhaps the most important factor was the change from a completely *laissez-faire*, utilitarian attitude to a more conservation-oriented philosophy of forest management. Much of this change is due to the work of William Goodrich Jones (1860-1950), the "Father of Forestry in Texas" (Maxwell and Martin, 1970). His accomplishments include leading the effort to establishing Texas Arbor Day (Feb. 22), promoting scientific forest management, surveying the forests of east Texas in 1899, and founding the Texas Forestry Association. His efforts eventually led to the appointment of a state forester and the establishment of Texas A&M’s Department of Forestry (Maxwell and Martin, 1970). Jones’ passion and commitment are evident in the following excerpt of his writing:

> The ghosts of our hacked, scorched, and wasted forests are already beginning to walk the land, and orators, expansionists, and future legislators are invited to listen to facts. Some who have tolled the death knoll of the forests have been called "Cassandra prophets," cranks, and calamity howlers. Recently a change has taken place and the men who have known so many things that were not so are no longer exploiting their learning. The crime of 1900 will go down to history and will be laid at the doors of Texas [sic] who cannot longer plead ignorance or lend an inattentive ear. The butchery of our timber and the shocking waste has sped on from year to year at an ever increasing rate and today we stand no longer as prophets but pointing to the end which comes in sight. When the forests are gone, great will be the lament from coast to western ranch, and to governors,

> legislators and mill-men will come to [sic] choice anathamas [sic] and invectives of an outraged people. (Jones, ca. 1900, reprinted in Maxwell and Martin, 1970)

In 1917, Article 16 of the Texas Constitution was amended. Section 59 established that the conservation and development of natural resources are "all hereby declared public rights and duties and the Legislature shall pass all such laws as may be appropriate thereto" (Vernon's Ann. Tex. Const. Art. 16, Sec. 59). Thus began the history of forest conservation in Texas.

Other early forest conservationists include John H. Foster and Eric O. Siecke, the first and second state foresters, respectively. Under Foster, the state forestry program was established and saved from the state legislature's efforts to scuttle it (Maxwell and Martin, 1970). During Siecke's twenty-five year tenure (1918-1943), the Department of Forestry at Texas A&M became the Texas Forest Service, and state forests were established in 1924, 1925, and 1927 (see Table 4). A Civilian Conservation Corps (CCC) performed many forest management duties during the Great Depression. Finally, Siecke was responsible for establishing the boundaries of several national forests, a duty delegated to him by the state legislature (see Table 4) (Maxwell and Martin, 1970). Additional supporters of Texas forest conservation in the first half of the twentieth century include several governors, legislators, and presidents of the Texas Forestry Association. Although the main thrust of conservation efforts was concentrated in the upland forests of east Texas, bottomlands also benefited somewhat, as small parcels of hardwood forest were located within the protected state and national forests (USFWS, 1985).

Table 4. State and National Forests Established in Texas, 1920-1940

State Forests	Acres	Year	National Forests	Acres	Year
E.O. Siecke	1,720	1924	Angelina	148,943	1935-36
I.D. Fairchild	2,630	1925	Davy Crockett	155,545	1935-36
W. Goodrich Jones	1,725	1927	Sabine	179,182	1935-36
John Henry Kirby	600	1927	Sam Houston	145,397	1935-36

(from Maxwell and Martin, 1970)

While early Texas conservationists struggled to enact sound forest management policy on the state level, the era of Theodore Roosevelt and Gifford Pinchot was under way nationally. A number of federal laws was subsequently passed between 1911 and 1933, which supported Texas' forest conservation efforts (Maxwell and Martin, 1970). The Weeks Law (1911) "established a pattern of state-federal cooperation in protecting watershed lands from fire and erosion and enabled the federal government to buy land for new national forests" (Maxwell and Martin, 1970). It was strengthened several times, most notably with the passage of the Clarke-McNary Act (1924), which provided the money to purchase land for the Texas National Forests. The Smith-Lever Act and Capper-Ketchum Act (1914 and 1928, respectively) established and expanded forestry the Extension Service's forestry programs. A forest research program was funded by the McSweeney-McNary Act (1928), which provided for a resource survey in Texas. Trees were planted in Texas' national forests as a result of the Knutsen-Vandenburg Act's authorization of a national tree-planting program (1930). Finally, the CCC was established and deployed in a variety of forest conservation and management tasks with the passage of the Emergency Conservation Act (1933) (Maxwell and Martin, 1970). These laws provided Texas conservationists with additional means to expand the state's forest preservation capacity.

More recent Texas statutes affecting forest conservation and preservation began to be passed in the 1970's. Title 1, Section 1.003 of the Water Code (1971) specifically declares forest conservation to be within the purview of the state's power (V.T.C.A., Water Code Section 1.003). Amendments to the Water Code, such as Section 11.149, address wildlife habitat issues and thus have the potential to affect bottomland forest conservation directly (McKinney and Rieff, 1986). Other amendments of the same year address issues of in-stream water uses, fish and wildlife protection, granting of development permits, and water quality; all of these affect the quality of bottomlands indirectly (McKinney and Rieff, 1986). In 1995, the Water Code was amended again to organize and establish the powers and responsibilities of the Texas Natural Resources Conservation Commission, which assumed the duties of enforcement of the Water Code, previously the bailiwick of the Texas Water Commission (V.T.C.A., Water Code Title 2). A very recent amendment to Title 5 of Texas Parks and Wildlife Code "delineates powers of government to regulate wildlife and endangered species through habitat preserves and habitat conservation plans" (V.T.C.A., Parks and Wildlife Code Sections 83.011-83.020).

A few of the more recent federal laws potentially affecting bottomland forest preservation include the Wilderness Act (1964) and National Wildlife Refuge System Administration Act (1966), which directly address protection of wilderness and habitat areas (USFWS, 1985). The Wild and Scenic Rivers Act (1968) slates certain rivers and riparian areas for protection, and the National Environmental Policy Act (1969) establishes general environmental regulations, such as requiring Environmental Impact Statements for any development project (USFWS, 1985). Judicious use of these and many other statutes could lead to progressive bottomland forest protection plans, when combined with careful research efforts.

Given the ecological benefits provided by bottomland hardwood forests, it seems clear that they are worth the effort to preserve and restore them. Moreover, the history of abuse and exploitation to which these ecosystems have been subjected in Texas seems to warrant more effective preservation efforts than have been made in the last century. Unfortunately, it is not clear exactly how much bottomland forest needs to be preserved, or what kinds of human intervention are needed to preserve it. Much depends upon a number of factors, e.g. the condition of the area to be preserved or restored, the surrounding land use, and the ultimate goals of the preservation or restoration effort. Also, since conservation biology and restoration ecology are young sciences, research methods are continually being developed. Despite the difficulties, efforts to study and preserve bottomland hardwood forests are being made. Chapters 2 and 3 show how two different approaches, field work and computer modeling, can improve ecologists' knowledge of the bottomland forest, and also help to determine the extent of preservation that may be necessary in a particular area.

CHAPTER 2

FOREST CHARACTERIZATION STUDY OF LAKE RAY ROBERTS GREENBELT

Introduction

Since wildlife habitat is one of the primary benefits that bottomland forests provide, and these forests are still disappearing in north Texas as a result of the factors discussed in Chapter One, research concerning how much forest is necessary to sustain resident species is very much needed. As wildlife habitat becomes more fragmented, corridors of similar habitat connecting these fragments become increasingly important. However, the extent of historical forestland is a debatable issue; even if a particular period in history is chosen as the ideal goal, experts disagree on the extent of unbroken forest alive at that time (Hodges, 1997; Hamel and Buckner, 1998). Colonization of tree species since the last Ice Age is also an ever-changing process (Hamel and Buckner, 1998). Moreover, river systems themselves are in a continual state of flux, as erosion, deposition, current flow, and many other factors change the shape of the a river over time (Forman, 1995). Thus, determining the optimum extent of unbroken, or at least connected, forest habitat based upon utilitarian goals may be a better choice than basing the decision upon historical conditions.

As stated in Chapter One, wildlife habitat is one of the primary benefits provided by bottomland hardwood forests. Studies have been done regarding the issue of forest corridor width, and its relationship to wildlife habitat. Everson and Boucher (1998) found that tree species richness increased with forest corridor width. Tischendorf and

Wissell (1997) and Haddad (1999) demonstrated that increasing forest corridor width resulted in asymptotic increases in the movements of small animals and butterflies, respectively. Skagen et al. (1998) showed that riparian habitat of any size was important to migratory birds in Arizona, and Perault and Lomolino (2000) found that the presence of corridors connecting fragments of old growth forest positively affected the populations of mammal species in the larger forest patches. For general purposes, Andreassen et al. (1995) recommend maximizing corridor width and structural variety while minimizing gaps in order to benefit the maximum number of species. Regarding riparian corridors, Forman (1995) recommends extending the corridor into the upland interior to facilitate movement of animal species, including upland interior species. However, in areas where discharge of pollutants threatens water quality, a wider corridor is needed to absorb these pollutants before they reach the stream channel (Forman, 1995).

While useful information regarding forest corridors can be gleaned from sources such as these, specific study of a riparian corridor in north central Texas was needed to make recommendations for that area. In 1997, an ecological survey of the bottomland forest within the Army Corps of Engineers land between the Ray Roberts and Lewisville reservoirs in north central Texas was begun. The Ray Roberts Greenbelt Corridor Study was undertaken to "explore how biodiversity assessment, habitat analysis, and landscape evaluations at various scales can provide conceptual guidelines for the design, evaluation, restoration, and management of riparian wildlife corridors (IAS, 1999)." Four major components make up the characterization study: a phytosociology study, an avian study, a habitat suitability study for avian species, and a mammalian study (Barry et al., 1999).

See Appendix A for a list of species found on the Greenbelt during the course of the characterization study. Barry (2000) and Hoffman (2001) analyzed data from this study and developed recommendations regarding riparian forest management for the north central Texas region. Their findings are presented in the discussion section of this chapter.

One component of the Greenbelt Corridor study was a phytosocial survey analyzing the Greenbelt forest with regard to its value as habitat for different species of birds and mammals, in both the narrow corridor areas and the larger patches. The purpose of the phytosocial survey was to gather relevant data about the forest, such as tree species counts, diameters of trees, successional stage, and canopy attributes. Various analytical techniques were used to determine how the importance of various species changes from one successional stage to another, and whether there is significant difference in physical forest characteristics between the larger patches of habitat and the narrow corridors of habitat that connect them.

Study Area

Lake Ray Roberts is a reservoir on the Elm Fork of the Trinity River. It is situated approximately 16 kilometers north of Denton, Texas (University of North Texas, 1995). After the construction of the dam, the Army Corps of Engineers established a greenbelt area that stretches from just below the dam at FM 455 to U.S. Highway 380, a linear distance of approximately 16 km (Barry et al., 1999). The set-aside area is intended for wildlife habitat and human recreational activity. Bottomland hardwood forest comprises one quarter of the nearly 2000 ha total area of the Ray Roberts Greenbelt (Barry et al., 1999). Figure 2 shows an aerial photograph of the Greenbelt.

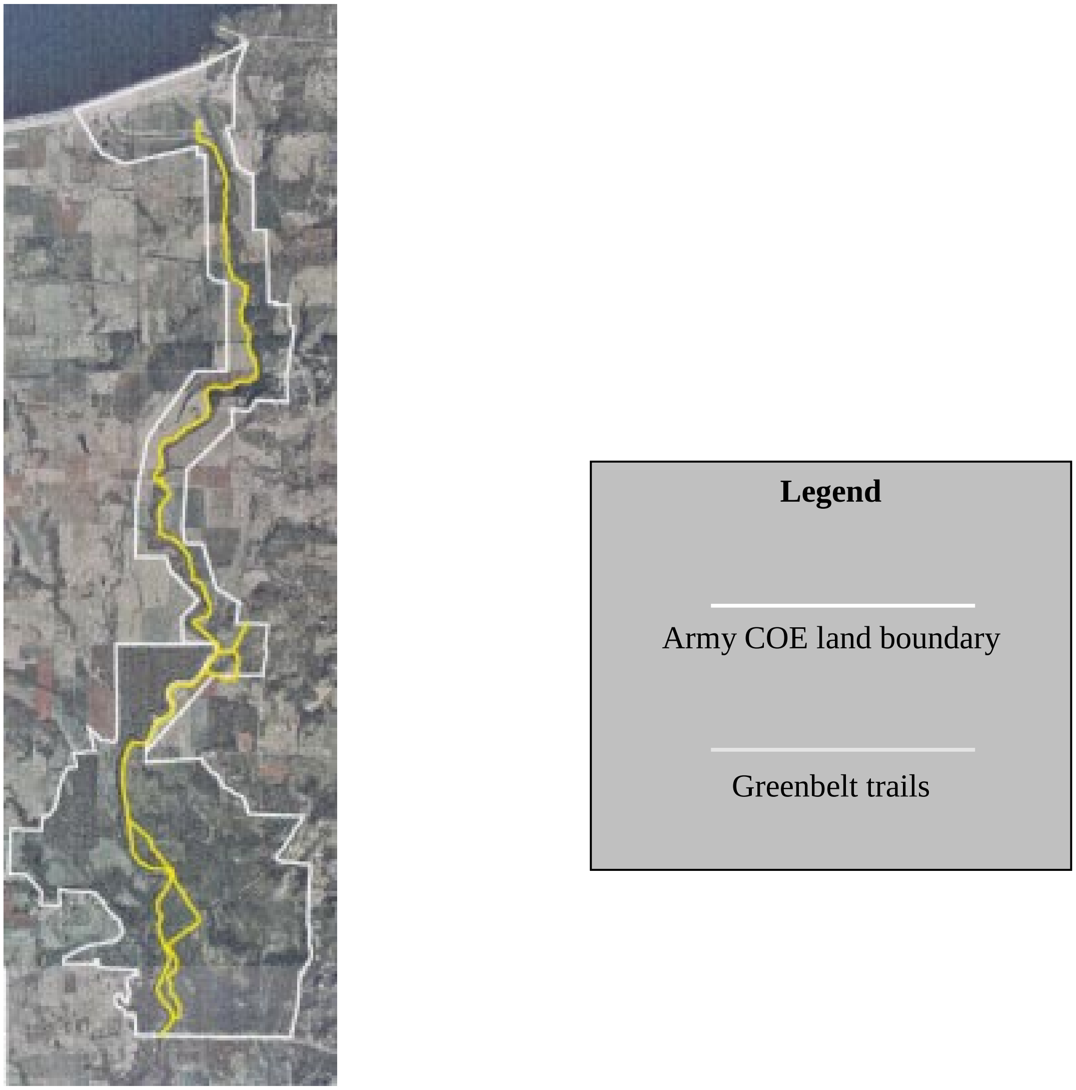


Figure 2. Lake Ray Roberts Greenbelt.

Materials and Methods

Study plots for the forest habitat characterization survey coincide with the avian survey plots in the Greenbelt corridor study. The first of these plots is located immediately south of Lake Ray Roberts dam, and plots occur every 250 meters in a southerly direction along the Elm Fork. The east-west position was determined using GIS, and located at the center of the forest patch or corridor at every 250-meter mark. Whether a plot lies east or west of the river depends upon whether the center of the forest habitat is located east or west of the river at that point.

Upon arrival at an avian plot, surveyors selected the area judged to be the most representative of the immediately surrounding forest as the forest characterization survey plot. The circular plots each had an area of approximately 100 m^2. Plot boundaries were determined using a 5.64 m rope pre-cut to the correct length. All stems of at least 10 cm in dbh within the plot were measured. The standardized height at which measurements were taken was 1.43 m above the base of the trunk (Oliver and Larson 1990). Measurements were made passing the tape under any twining vines if possible; otherwise the vines were included in the measurement and 1-3 cm deducted from the value obtained, according to vine thickness. All trunks split below 1.43 m from the base were measured as separate stems (Oliver and Larson 1990).

Forest seral stage was another category of data recorded at each plot. For this classification, the average dbh of overstory trees, stem density, and species composition within visual range were estimated. These allowed samplers to classify the area around each plot as one of the following seral stages: stand initiation (seedlings or saplings), stem exclusion (pole timber), understory reinitiation (saw timber), and old growth.

Canopy assessment, including number and mean height of layers was a substantial component of the forest survey. Number of canopy layers was determined by first noting presence or absence of each of the following: ground/herb, shrub, understory, midstory, canopy, and emergents. Presence of a layer was judged by whether enough of that layer occurred in the immediate area to afford perching or foraging opportunities for birds. Mean height of each layer was obtained by selecting a representative member to measure, either directly with a meter tape (ground and shrub) or using a clinometer (understory, midstory, canopy, and emergents).

For the fall characterization survey, plots were selected along the corridor in a stratified-random manner. The corridor was divided into lengths encompassing five or six avian plots. Then five or six numbers representing distances within those lengths were selected randomly for placement of a survey plot. The locations were determined from the aerial photos used to find the avian plots. Each plot was surveyed in the manner described above for the avian plots. Raw data from the phytosocial survey of the Greenbelt characterization study can be found in Appendix B.

Analysis of the data began with calculating importance values for each tree species, plus snags, over the entire forest for the avian plots and again for the random plots. The tree data were then separated according to successional stage, and importance values were again calculated for each stage. This was done for both avian and random plots. Complexity and foliage height diversity indices were calculated for each plot to provide additional attributes for comparison. The equation for the complexity index is

$$\text{CI}=\text{Density}*\text{Sum of Basal Area}*\text{Canopy layers}*\text{Species Richness}*10^{-5}$$

(adapted from Holdridge et al. 1971 and Shear et al. 1996). The foliage height diversity equation is $\text{FHD} = -\Sigma p_i \log p_i$, where p_i = the proportion of the total canopy height of canopy layer i (FHD is the H’ diversity index; Brower et al. 1998, MacArthur and MacArthur 1961).

The DOQQ data set assigned a category of corridor or patch to each individual avian survey plot according to the size (width, area) of the forest at that plot and the distance to the nearest edge. Importance values for the different tree types were recalculated for corridor and patch plots. The equation for importance value is

$$IV = (\text{Relative Density} + \text{Relative Dominance} + \text{Relative Frequency})/3$$

(Brower et al. 1998). Percentage of similarity was the metric adapted to compare importance values between corridor and patch areas. The equation used for percent similarity is

$$PS = \Sigma \text{ minimum } (p1i, p2i)$$

where $p1i$ is the importance value of species i in class 1 (corridor plots) and $p2i$ is the importance value of species i in class 2 (patch plots) (Brower et al. 1998; Dyer 1978). Percent similarity was also used to compare the importance values of the random plots to the corridor avian plots and to the patch avian plots. Finally, the total-forest values were compared between the avian plots and the random plots using this index.

Complexity, foliage height diversity, and canopy coverage were compared between corridor and patch areas using the Mann-Whitney U test. They were also compared between avian and random plots. Total density, total dominance, snag density, and large snag (>25 cm DBH) density were the last items compared, and these were also done between the corridor and patch plots and between the avian and random plots. See Table 5 for a summary of the metrics used in the analysis of Greenbelt data.

Table 5. Summary of Metrics and Tests in Greenbelt Characterization Study

Metric/Test	Plots
Complexity Index (CI) Foliage Height Diversity Index (FHD)	All
Importance Value (IV)	All Avian All Random Each Successional Stage- Avian Each Successional Stage- Random Avian Corridor Avian Patch
Percent Similarity of IV Mann-Whitney Total Density, Total Dominance, Snag Density, Large Snag Density, CI, FHD, Percent Canopy Cover	Avian Corridor v. Avian Patch Avian Corridor v. All Random Avian Patch v. All Random All Avian v. All Random

Results

For the avian plots, calculation of importance values for the entire forest revealed Hackberry, Green Ash, Snag, Cedar Elm, and American Elm to be the most important trees from a habitat perspective, i.e. these were the trees with importance values greater than 5. The actual values were 34.94, 19.75, 11.23, 8.82, and 5.25, respectively. Importance values were then calculated within each successional stage, and the values of Hackberry, Green Ash, Snag, Cedar Elm, and American Elm were plotted on a graph to determine the likely trend for each as the forest proceeds through its successional stages (see Figure 3). The values for all of these tree types were <10 in the Stand Initiation stage. Hackberry increased dramatically to a high of 36.24 in Understory Reinitiation, then declined slightly to 32.03 in the Old Growth stage. Green Ash showed a similar, though less dramatic trend, increasing to 22.41 in Understory Reinitiation and declining to 14.71 in Old Growth. Cedar Elm began at zero in Stand Initiation, climbed to 11.75 in Stem Exclusion, dropping slightly in Understory Reinitiation, and going back to zero in Old Growth. American Elm displayed a slow, steady increase from zero in Stand Initiation to 5.68 in Old Growth. Snags showed the most erratic pattern, beginning at 8.99 and increasing to 16.49 in Stem Exclusion, then dropping slightly below the Stand Initiation value to 7.54 in Understory Reinitiation before soaring to 28.33 in Old Growth. All values are listed in Table 6.

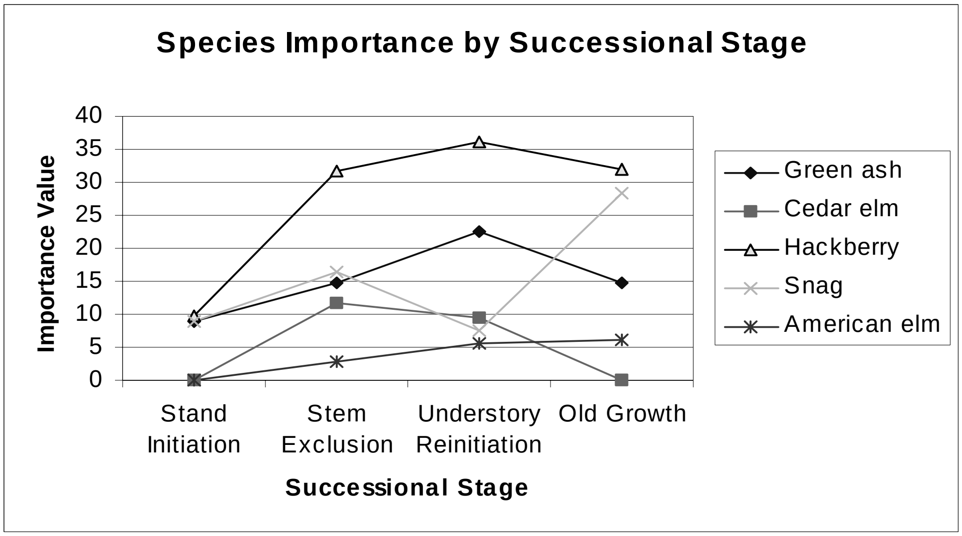


Figure 3. Avian plot species importance by successional stage for the most important forest species and snags.

Table 6. Avian Plot Species Importance Values for All Forest Species and Snags

Species	Stand Initiation	Stem Exclusion	Understory Reinitiation	Old Growth
Green ash	8.84	14.81	22.41	14.71
Cedar elm	0	11.75	9.34	0
Bois d'arc	0	3.82	1.03	0
Hackberry	9.59	31.65	36.24	32.03
Snag	8.99	16.49	7.54	28.33
Chittamwood	0	0.36	0	0
Red Mulberry	0	0	3.04	3.68
Black walnut	0	1.09	0	0
Bur oak	0	0	2.02	11.33
Honey locust	13.93	1.88	0.39	0
Hawthorn	0	0	0.39	0
Slippery elm	0	0	2.82	0
Shumard oak	0	0	0.4	0
Box Elder	0	4.46	2.9	0
Pecan	0	3.82	2.77	3.71
American elm	0	2.91	5.68	6.21
Cottonwood	33.5	2.61	2.51	0
Post oak	0	1.42	0	0
Blackjack oak	0	1.09	0	0
Black willow	25.16	1.84	0	0
Sycamore	0	0	0.54	0

For the random plots, the species with total-forest importance values greater than 5 were Hackberry, Slippery Elm, American Elm, Green Ash, Snag, and Cedar Elm. The actual values were 22.00, 17.52, 12.19, 11.49, 11.16, and 11.07 respectively. These species were graphed according to their importance values over the different successional stages (see Figure 4). This time, all species had values <10 in the Stand Initiation stage except for Green Ash, which was 24.79. Green Ash then dropped below 15 and remained near 15 through the Old Growth stage. Cedar Elm soared to 28.20 in the Stem Exclusion stage, but plummeted to below 5 by Old Growth. Hackberry climbed to 30.03 in the Understory Reinitiation stage, then fell nearly 10 points in Old Growth. Snags had values just above 8 in the first and last stages, with values near 14 in the middle stages. Slippery Elms had the lowest values, 2.96 initially, then dropping below 1 for two stages, and peaking at 6.59 in the last stage. American Elm values held steadily near 8 for two stages, then leapt to around 18 for the last two stages. Table 7 lists the values for all these species in all stages.

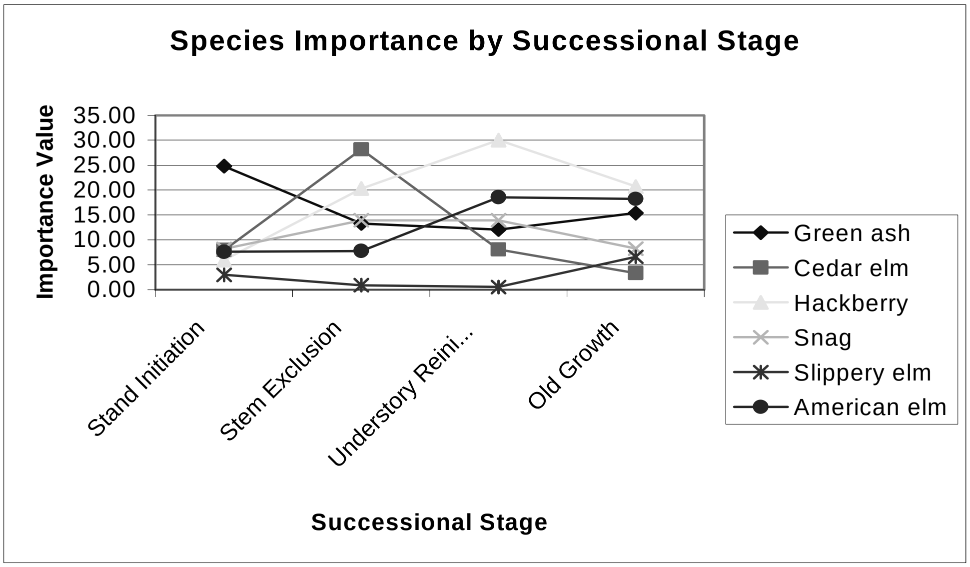


Figure 4. Random plot species importance values by successional stage for the most importance forest species and snags.

Percent similarity analysis of importance values between different data sets revealed a range of 69.31% (avian patch vs. total random plots) to 76.52% (avian corridor vs. avian patch plots). The mid-range similarity values were 71.79% (avian corridor vs. total random plots) and 71.91% (total avian vs. total random plots). Table 8 contains all percent similarity values.

Table 7. Random Plot Species Importance Values for All Forest Species and Snags

Species	Stand Initiation	Stem Exclusion	Understory Reinitiation	Old Growth
Green ash	24.79	13.28	12.06	15.34
Cedar elm	7.96	28.20	8.04	3.35
Bois d’arc	3.01	1.07	1.36	0.00
Hackberry	5.96	20.27	30.03	20.68
Snag	8.18	13.95	13.93	8.26
Chittamwood	0.00	0.85	0.00	0.00
Red Mulberry	0.00	0.84	3.37	4.93
Black walnut	0.00	0.00	0.00	0.00
Bur oak	0.00	3.22	3.90	10.82
Honey locust	0.00	0.00	0.51	0.00
Hawthorn	0.00	0.00	0.00	0.00
Slippery elm	2.96	0.91	0.51	6.59
Shumard oak	2.89	3.60	0.00	0.00
Box Elder	7.84	2.42	5.18	7.01
Pecan	16.09	0.00	1.06	0.00
American elm	7.61	7.78	18.59	18.19
Cottonwood	3.85	0.84	0.56	0.00
Post oak	0.00	0.00	0.00	0.00
Blackjack oak	0.00	0.00	0.00	0.00
Black willow	8.84	1.09	0.00	0.00
Sycamore	0.00	0.00	0.91	0.00
Mesquite	0.00	0.84	0.00	0.00
Chinaberry	0.00	0.85	0.00	0.00
vine	0.00	0.00	0.00	4.82

Comparisons of complexity indices, foliage height density values, canopy coverage, total density and dominance, and snag and large snag density were made among the different data sets using a Mann-Whitney U test. These were done in the following configurations: avian plots vs. random plots, avian patch vs. avian corridor plots, avian patch vs. random plots, and avian corridor vs. random plots. Most of the comparisons showed no significant difference at the 0.05 alpha level. The comparisons that did show a significant difference, or at least came close, were the total avian-total random complexity index (*p* value = 0.05), the avian patch-total random complexity index (*p* value = 0.06), and the avian patch-total random dominance comparison (*p* value = 0.07).

Table 8. Percent Similarity in Importance Values for All Species, by Data Set Comparison

Comparison	Percent Similarity
Avian Corridor vs. Avian Patch	76.52
Avian Corridor vs. Total Random	71.79
Avian Patch vs. Total Random	69.31
Total Avian vs. Total Random	71.91

Discussion

The results of the importance value analysis with respect to successional stage show, overall, an expected pattern in the avian plots. Green Ash, Cedar Elm, Hackberry, and American Elm, all species associated with earlier successional stages peaked in importance in Understory Reinitiation or earlier and declined in Old Growth. Snag importance value, however, increased dramatically in the Old Growth stage. This would seem to indicate an increase in suitable habitat for species that rely on standing deadwood as the forest succeeds to Old Growth. Currently, however, Old Growth patches are rare in the Lake Ray Roberts Greenbelt, and if past development patterns are continued, these patches may be lost along with the opportunity to increase this desirable habitat in the future.

In the random plots, the pattern is less clear. The rise in the Green Ash and Slippery Elm importance values and the decline in snag importance values, seem to run counter to the trend established by the avian plots. This could be due to the small number of the old growth and stand initiation plots sampled in the Greenbelt. It could also be due to error in identification of successional stage during the fall survey. There was some difficulty distinguishing between Slippery Elm and American Elm species during the fall survey as well.

The percent similarity analysis shows greater than two-thirds similarity for all data set comparisons, and greater than three-quarters similarity for the avian corridor and avian patch plot comparison. This would seem to indicate that, concerning physical habitat characteristics, little difference exists between the areas designated as corridor and those designated as patch. If so, this result supports the practice of providing corridors connecting larger patches of habitat, demonstrating that there is a continuation of habitat value from the patch to the corridor. The fact that there was no significant difference between corridor and patch areas with regard to complexity indices and foliage height diversity is further evidence of the similarity between the two sizes of habitat area. Indeed, the lack of significant difference in most of the data set comparisons, regardless of the metric compared, seems to indicate that the Greenbelt forest has somewhat similar habitat characteristics throughout. Only three of the comparisons come close to having significant difference at the $\alpha=0.05$ level, and two of them are complexity index comparisons. The reason for this is not clear; it could simply be an artifact of the metric itself.

Habitat fragmentation is an ecological issue that is becoming increasingly urgent as more land is developed for human use. As fragmentation increases, the need for corridors connecting habitat patches rises. This study indicates that it may be possible to maintain much of the habitat value present in larger patches along the corridors connecting them. Of course, further research on actual patterns of animal usage and movement through the corridors to determine whether the apparent habitat value is truly functional. Given the importance of the bottomland forest ecosystem as wildlife habitat, corridors connecting fragments of this valuable and productive habitat are essential.

Using avian demographic data from the Greenbelt corridor study, Hoffman (2001) found a positive correlation between corridor width and forest interior species richness. Similarly, a positive correlation occurred between distance to nearest edge and forest interior species. Analysis of the curves of best fit to the data revealed similar results; to maximize forest interior species richness, a forest patch should be approximately 450 m wide, with approximately 200m to the nearest edge (Hoffman, 2001). Thus, managing the Greenbelt forest to maximize forest interior bird species richness would involve widening corridor stretches to at least 200 m on each side of the river.

Applying landscape analysis to the same data, Barry (2000) found that amount of forest was the most common landscape factor affecting both species richness and abundance in the forest corridors. Furthermore, the entire avian community, not only the forest interior species, were affected by the amount of forest cover, width of the corridor, and distance to the nearest forest patch containing interior forest. Corridor width thresholds ranged from 200-470 m, with upper quartiles from 200-210 m in the Barry study. The distance to the nearest interior patch proved to be an important consideration; for conservation of forest interior bird species, “efforts should be made to make these corridors as short as possible, while extending the area of the extant patches as much as possible" (Barry, 2000). Barry's recommended average maximum distance is 125 m. Finally, habitat suitability analysis for selected bird species corroborated the results of the phytosocial study; the corridor and patch areas of the Greenbelt forest showed no significant differences with regard to habitat value (Barry, 2000).

If the management goal is to provide optimum habitat for birds, particularly forest interior species, then Barry and Hoffman have delineated specific recommendations with regard to forest corridors on the Ray Roberts Greenbelt. In summary, they are to provide a minimum of 200 m width on either side of the river, to provide a minimum of 35% forest cover within 1 km of the Greenbelt, and to maximize larger forests patch areas, connecting them with corridors of 125 m or less (Barry, 2000; Hoffman, 2001). Broadening the management goal to include a greater variety of animals, Greenbelt managers could expand corridor width to include upland interior, as Forman (1995) suggests. Since much of the Greenbelt corridor is narrower than the minimum recommended width of 200 m, restoration from other land uses would be necessary.

Successful restoration efforts require detailed information about the ecosystem being restored. Fortunately, one relatively large and pristine area of bottomland forest remains on the Greenbelt; it was the subject of a recent intensive study conducted by Barry and Kroll (1999). The results of that study were used to calibrate the ZELIG forest simulation model. Computer simulation may be able to provide information that could assist the restoration process. For example, it could give an approximation of the amount of time necessary to achieve the desired climax forest community. Additionally, if restoration efforts were to extend from the river bottom into the upland terrace, a series of simulations could demonstrate changes in the forest across a variety of spatial gradients. The third chapter provides a summary of Barry and Kroll's study, and describes the process of calibrating the model.

CHAPTER 3

USING THE FOREST GAP MODEL ZELIG TO SIMULATE A REMNANT BOTTOMLAND FOREST IN THE RAY ROBERTS GREENBELT

Introduction

Computer modeling is one way to evaluate the potential impacts of different forest management techniques and environmental stressors (Acevedo et al., 1997). With regard to corridor widths, it could help to determine the feasibility of achieving specific optimum width recommendations, such as Barry's and Hoffman's, based on a site's physical characteristics (e.g. soil moisture). It could also demonstrate the changes in forest species composition along transects from floodplain to upland in areas where the riparian corridor extends into the upland terrace, following Forman's corridor width recommendation.

The ZELIG model, developed by Dean L. Urban, is a type of forest simulator known as a gap model. Gap models, unlike other types of forest simulators, emphasize the effects of environmental factors on forest growth and composition as the simulation runs (Acevedo et al., 1995). They can also be grouped into the category of science-based models, which form something of a partially data-driven middle ground between statistical (empirical) and mathematical (theoretical) models (Rogers and Johnson, 1998). Science-based models "possess realism and generality but sacrifice accuracy" (Rogers and Johnson, 1998). Even so, gap models contain enough predictive power to be useful for a variety of purposes (Urban and Shugart, 1992). As such, ZELIG is a general ecological model that can be modified to suit specific sites and data sets (Urban, 1993). Further details about gap models in general, and ZELIG in particular, can be obtained from Urban and Shugart (1992).

For this project, the ZELIG model was calibrated with data from a patch of bottomland hardwood forest in north central Texas. Comparing the model's output with known ecological data of this type is a common method of testing gap models (Urban and Shugart, 1992). The purpose of the project was to determine the potential of the ZELIG model to simulate the bottomland forest of the Lake Ray Roberts greenbelt. After the simulations were run, the results were analyzed, and difficulties modeling various aspects of the forest noted. Suggestions for future model study and experimentation were advanced.

Data Sources

A phytosocial study of the remnant bottomland forest by Barry and Kroll (1999), reviewed below, provided calibration data for the model. The goal was to approximate the species composition of the Greenbelt forest as indicated by the importance values obtained by that study at some point within the model simulation. A window of 300-500 years was considered to be a reasonable estimated range, since the forest would be mature by that time. Allowance was made for possible succession beyond the community seen in the Ray Roberts Greenbelt remnant forest, since it did not represent the oak-dominated climax community presented in the ecological literature.

Some tree parameter values for the model, such as maximum height, maximum age, and crown type, were estimated from general literature (Vines, 1984; TFS, 1990; Grimm, 1962; Sargent, 1949; Preston, 1961; USDA, 1990; Little, 1998).

Weather data were obtained the National Oceanic and Atmospheric Administration (NOAA, 1992), and the National Solar Radiation Database (NSRD, 1992). Specific measurements, such as height and diameter data for individual trees were obtained from the field for this project. Values for the soil parameters were assigned according to soil textures within the patch, as listed in the Natural Resources Conservation Service's Soil Survey Geographic (SSURGO) database (1995).

Phytosocial Study of Ray Roberts Greenbelt Remnant Forest

The greatest area of protected riparian forest in Denton County is the Lake Ray Roberts Greenbelt. One large (93 ha) relict bottomland hardwood forest within the Greenbelt containing some old growth patches is located approximately two-thirds of the way down the Elm Fork, nearer to U.S. Highway 380. A variety of tree species can be found here, including green ash (*Fraxinus pennsylvanica*), cedar elm (*Ulmus crassifolia*), hackberry (*Celtis occidentalis* and *C. laevigata*), bur oak (*Quercus macrocarpa*), pecan (*Carya illinoensis*), black walnut (*Juglans nigra*), and bois d'arc (*Maclura pomifera*). A phytosocial study of this remnant was conducted in 1997 to determine some of the major tree community features (Barry and Kroll, 1997). The results of this study provide a model bottomland forest to guide managers in their preservation and restoration efforts. Figure 5 contains an aerial photo of the Greenbelt with detail of the relict bottomland forest.

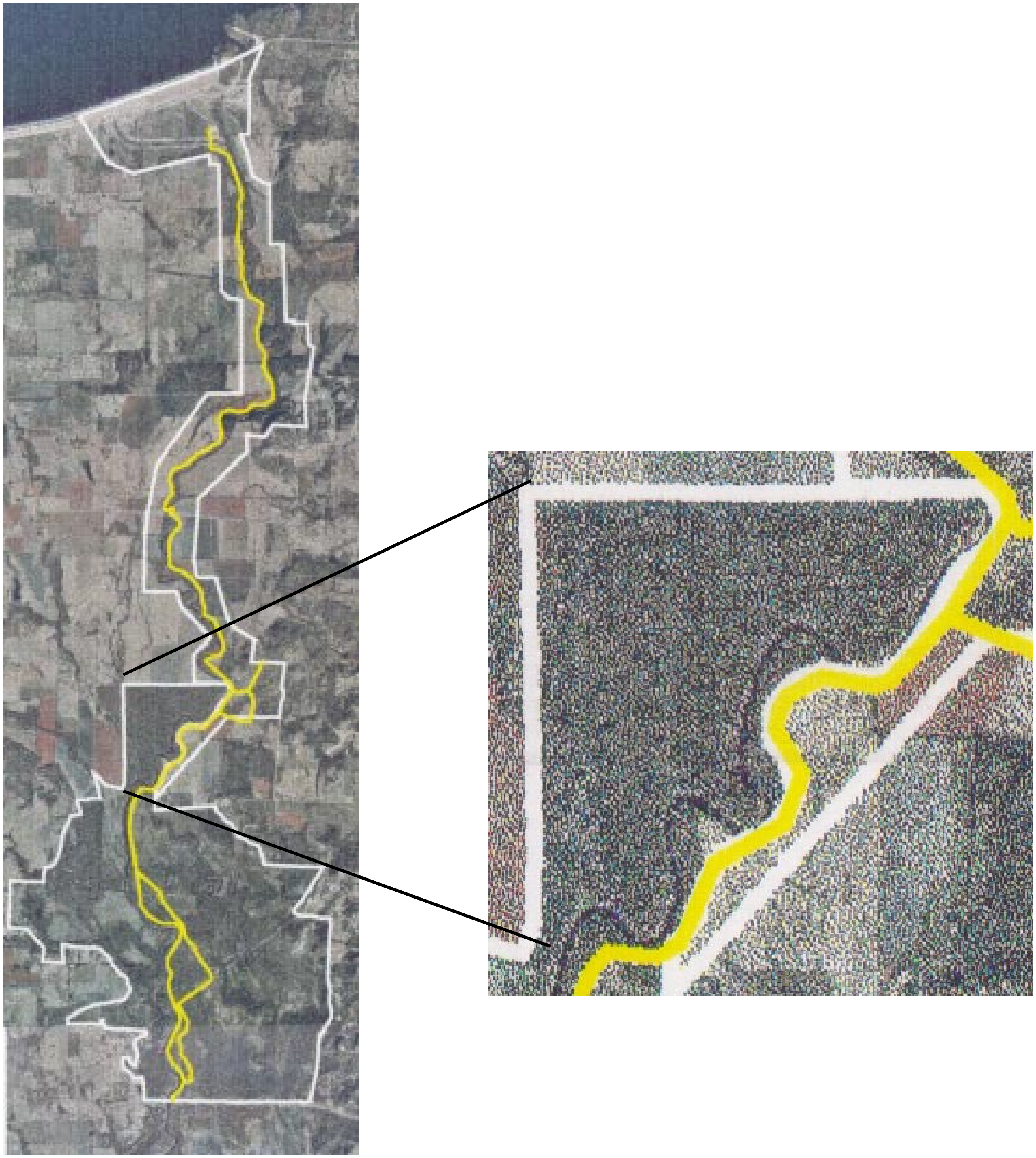


Figure 5. Aerial photograph of the Ray Roberts Greenbelt study area, with enlarged detail of the relict bottomland forest.

Methods

For this study, 128 circular, 100 m^2 plots were laid out in a grid. Standard forestry metrics such as diameter at breast height (dbh), density, and frequency were measured in each plot. Out of a total of 972 trees, twenty-four Hackberry specimens, thirteen Green Ash, and four Bur Oak were randomly selected from all size classes for age determination. Using a sixteen-inch increment borer with a 0.2-inch diameter, surveyors took cores from each tree at breast height. Rings were double-counted and the cores replaced and sealed with mud (Barry and Kroll, 1999).

Relative dominance (basal area per unit area sampled), relative density (number of stems per hectare), and frequency of occurrence were calculated for each species. Importance values were obtained by averaging the metrics. Linear regressions were run on the age data for Hackberry, Green Ash, and Bur Oak, with dbh as the independent variable and age class as the dependent variable. The regression curves were tested at $\alpha = 0.05$, and 95% confidence limits obtained from descriptive statistics. Relative similarity of individual plots was determined with cluster analysis. Specified cluster designation was obtained with K-means clustering, using the complete linkage joining algorithm to maximize differences between plot distances, the percent disagreement distance algorithm for categorical data (presence/absence), and the city-block distance algorithm for continuous data to maximize effects from extreme values (Barry and Kroll, 1999).

Results

Thirteen tree species, plus snags, were sampled in this study; nine more species were encountered, but did not fall within a sampling plot. Of the species sampled, the ones with the highest importance values were Hackberry (40.19%), Cedar Elm (28.13%), and Green Ash (9.51%). Snags, an important component of bottomland forests, were found to have an importance value of 7.17%. All other species' importance values were less than 5%. Table 9 lists importance values for all species sampled; refer to Table 2 for a list of all twenty-four species encountered in the study. According to these results, the classification for this bottomland forest is hackberry/elm/ash (Barry and Kroll, 1999).

Table 9. Importance Values for Species of the Relict Bottomland

Species	**Relative Dominance**	**Relative Density**	**Relative Frequency**	**Importance Value**
Hackberry	53.61	39.81	27.14	40.19
Cedar Elm	38.33	23.56	22.49	28.13
Green Ash	4.17	12.14	12.22	9.51
Snags	1.29	7.51	12.71	7.17
Black Walnut	0.15	4.22	5.62	3.33
Bur Oak	1.98	2.37	5.13	3.16
Chittamwood	0.15	1.95	4.40	2.17
Bois d'arc	0.23	2.26	3.67	2.05
Hawthorn	0.05	2.47	2.20	1.57
Box Elder	0.02	1.44	0.73	0.73
Red Mulberry	0.00	0.72	1.47	0.73
Slippery Elm	0.00	0.51	0.74	0.42
Eve's Necklace	0.00	0.51	0.49	0.33
Shumard Oak	0.02	0.31	0.49	0.27
Honey Locust	0.00	0.11	0.25	0.12
Paper Mulberry (shrub)	0.00	0.11	0.25	0.12
Sum	100.00	100.00	100.00	100.00

(Barry and Kroll, 1999).

The regression analysis of the dbh and age data for Hackberry and Green Ash showed a positive correlation of age to dbh; $R^2 = 0.68$ ($p < 0.0001$) and $R^2 = 0.7088$ ($p < 0.0003$), respectively. The Bur Oak data were not analyzed with a linear regression because of small sample size. Instead, an average ratio of 2.3 years per cm of diameter was calculated. Table 10 contains the formulae for the age estimations. Cluster analysis of plot metrics and presence/absence of species revealed the patchy nature of the forest. Patchiness is observed in both species composition and association. Fourteen classification clusters were found at the 50% relative dissimilarity level. The 5 category K-Means clustering showed that many spatially adjacent plots are not clustered in terms of species composition (Barry and Kroll, 1999). Extreme patchiness of this kind is consistent with the characteristics of riparian bottomland forests, whose species tend to vary greatly with differences in micro-topography and distance from the river (Hodges, 1997).

Table 10. Allometric Formulae for Age Estimation

Species	**Age Estimation Formula**	**95% Confidence Limits**
Hackberry	age = (1.7015*dbh) + 7.4975	+/- 0.03*dbh
Green Ash	age = (1.0175*dbh) + 14.597	+/- 0.23*dbh
Bur Oak	age = 2.3*dbh	+/- 0.38*dbh

(from Barry and Kroll, 1999)

Discussion

The dominance of the hackberry, cedar elm, and green ash species, and their wide distribution throughout the size classes, indicate that the hackberry/elm/ash association is replacing itself and maintaining itself as a climax community. Bur and Shumard Oaks, while not common, are present in large enough numbers, both as mature trees and as seedlings, to indicate that succession to the oak-hickory community described by Hodges (1997) could occur. Indeed, the change in hydrology brought about by the Ray Roberts dam may be assisting the change in species composition. Drier soils and absence of flooding have encouraged the propagation of Black Walnut and Bur Oak seedlings. Additionally, these conditions do not favor the hackberry/elm/ash association, which is adapted to wetter environments. It is conceivable, then, that the forest could eventually succeed to an association of oaks and walnuts, and become a classic old growth or late-successional bottomland forest. Currently, the forest as a whole can be classified as transitional old growth, based on the classification system of Oliver and Larson (1990), although small patches of true old growth can occasionally be found within it (Barry and Kroll, 1999).

Studies like this are important because very little detailed information exists about the condition of bottomland forests in north Texas. The phytosocial analysis reveals a remnant that can be taken as a model for restoration of degraded bottomlands, and as a baseline for comparison with other existing bottomland forests. This is particularly true since Barry and Kroll's study is a characterization of the forest itself, whereas many of the recent studies of bottomlands have been conducted as wildlife habitat studies. The methodology can be used as a template for monitoring the health of forests across the area. It may also be helpful in developing and evaluating restoration efforts. For this project, it provided empirical data for the calibration of the ZELIG model for simulation of bottomland hardwood forests in north central Texas.

ZELIG Model Calibration Process

Methods

As stated above, the model parameter values were calculated using field data and literature. Site parameters include all the values relating to soil, such as depth, profile, wilting point, and fertility. The first three of these were estimated as a function of topography and soil type. Fertility was estimated near the high end of the scale (from <5 to 25), since bottomland hardwood forests are highly productive systems with histories of sediment deposition on their sites. Site parameters also included the climate variables of temperature, precipitation and solar radiation, which were needed to calculate potential evapotranspiration (PET). These were obtained from a meteorological source such as NOAA. Species parameters for ZELIG include maxima for age, height, and diameter at breast height (dbh) for each species represented in the model. These were obtained directly from field guides and natural history literature. The particular species to be modeled are known from the Ray Roberts Greenbelt characterization study. Other parameters, such as shade tolerance, nutrient response class, and seedling establishment rate, were researched in more detail from botanical literature. ZELIG's offline support program, WEATHER, estimated temperature tolerance limits for each species, while growth rates were estimated allometrically in Splus. Height allometry parameters were calculated from non-linear regression of tree height to DBH. Raw data for the regression were obtained from the field measurements of height and dbh of individual trees. Other allometric parameter values were assigned according to crown type. All these values were stored in the input file of the ZELIG model.

Prior to running the forest model, data for ZELIG's input files were obtained from a variety of sources. Values for parameters directly related to the different tree species were estimated from forestry literature. The Silvics Manual online (USDA, 1999) provided information, such as shade and drought tolerance, geographic range, competitive fitness, and vegetative reproductive ability, from which many of the input parameters were estimated. Other parameters, such as maximum age, height, and diameter, were obtained from field guides and natural history sources (Vines, 1984; TFS, 1990; Grimm, 1962; Sargent, 1949; Preston, 1961). Weather data from NOAA (1992) was used to obtain maximum and minimum growing degree-days for each species, based on the geographic ranges given in Silvics. The process of determining degree-days is discussed below.   This study required temperature and precipitation records for the area, from 1895-1989 (NOAA, 1992), and solar radiation data for Fort Worth from 1961-1990 (NSRDB, 1992). Information on soil types in the Greenbelt forest was obtained from the Soil Survey of Denton County (NRCS, 1980), and the SSURGO database (NRCS, 1995).

The ZELIG model requires three input files to run a forest simulation. Examples of these files are shown in Appendix C. The first is the control driver file, which simply determines the size of the plot matrix, the number of years to run the simulation, the time interval at which to print the results, and the like. The site driver file contains information about the site of the forest simulation. Included in it are the latitude, longitude, and elevation of the area. These are followed by theta, phiB, phiD, and light extinction parameters, all of which have default values, which were used for this simulation. Tree size and maximum canopy height complete the top grouping of parameters. Tree size is given as 100 m^2, a general estimate of the total canopy coverage of one of the largest trees in the forest. Maximum canopy height is also estimated based on the maximum height of the largest tree species on the site (Acevedo et al., 1997).

The next section of the site file contains soil data. ZELIG can simulate up to nine types of soil. For each soil type, the number of layers must be given; ten is the maximum (default) value. Also, soil fertility must be estimated, on a scale of 1-25, 25 being maximum fertility. Since the Ray Roberts Greenbelt is on a major stream bottomland, the soil fertility was estimated at a value of twenty. Depth in centimeters must be given for each soil layer, and again the default is ten. Other values for soil are the field capacity and wilting point (per layer), both of which were obtained from values in the ZELIG manual for silty clay loam, the closest soil type to the Ovan Clay found in the Greenbelt. Soil type information was obtained from the Soil Survey of Denton County (NRCS, 1980).

Climate parameters follow the soil parameter values. The first two lines contain average temperatures (in degrees Celsius) and their standard deviations for each month. Average monthly precipitation levels (cm) and their standard deviations are contained in the next two lines. Average monthly solar radiation data follows the precipitation data. As mentioned above, temperature and precipitation data for the Greenbelt site were obtained from NOAA (1992), and solar radiation from the NSRDB (1992). The bottom of the site file contains a digital soils map. It is a matrix of soil types to be simulated, the number of rows and columns of which are stated in the control file. Since the SSURGO database (NRCS, 1995) shows that the Ovan Clay, resembling a silty clay loam, underlies almost all of the Greenbelt forest, silty clay loam was the only soil type simulated.

The third input file required by the ZELIG model is the species driver file. In order to simplify the modeling process, only the top five species from the relict bottomland were selected to model. These species were selected by analyzing the results from the Barry and Kroll study. Hackberry, Cedar Elm, Green Ash, Black Walnut, and Bur Oak had the highest importance values; all were greater than 3.0 (refer to Table 9). For that study, however, snags were measured, and found to have an importance value of 7.17. Since ZELIG does not include snags in its output, only the top five living species were selected. Moreover, ZELIG uses an alternative calculation for importance value; it excludes relative frequency from the equation. The equation for ZELIG's importance value calculation is IV = (Relative Density + Relative Dominance)/2. Consequently, the importance values for the top five species were recalculated as though they were the only species, and recalculated again using only relative density and relative dominance in the equation (see Table 11). Finally, Pecan was substituted for Black Walnut, because most of the small Black Walnuts were very likely misidentified Pecans. The importance value for Pecan was estimated to be slightly less than that of Bur Oak (Barry, 2000).

Table 11. Top Five Importance Values Recalculated

Species	**Importance Value (Top 5 spp only)**	**Importance Value (Rel. Dens. And Rel. Dom. only)**
Hackberry	46.81	51.52
Cedar Elm	32.91	33.88
Green Ash	11.95	9.50
Black Walnut	4.34	2.64
Bur Oak	3.99	2.45
sum	100	100

ZELIG's species file lists several species and environmental parameters for each tree species. Maximum age (Amax), maximum diameter (Dmax), and maximum height

(Hmax) are the first three species parameters. These were all estimated from the Silvics Manual and other tree literature. Two parameters, b2 and b3, are coefficients obtained from an allometric ratio of diameter to height. This allometry was performed using a specially written program in Splus. The equation for the calculation is $H = h_1[1\text{-}\exp(h_2D)]^{h3}$, where h_1 is the maximum height for a particular species, D is diameter, and h_2 and h_3 represent the height and steepness of the curve, as determined by regression. A growth rate value (g) is also listed for each species. It can be obtained by using ZELIG's offline program GROW, but in this case it was obtained from a special Splus program. Growth patterns are approximated by the life form parameter (lf). The ZELIG manual lists nine codes that correspond to different tree genera. Of these nine codes, only the codes for *Quercus* (8) and Other Deciduous (9) were needed. Finally, reproductive success is estimated with the parameters Seed, NSprt, and Sdmax. They represent seedling establishment rate, capability to resprout from stumps, and the maximum diameter at which stump sprouting will occur, respectively. The first two are values between 1 and 5, and represent each species' rank relative to the others. All three of these were estimated as nearly as possible from the Silvics manual.

The environmental parameters approximate several environmental conditions required by each species for growth. First among these are minimum (DDmin) and maximum (DDmax) temperature limits, estimated as degree-days. These were obtained by noting the northern and southern limits of the natural range of each tree species, as given in the Silvics Manual. Site input files were developed for each of the range limits for each species, and the offline program WEATHER was run on each new site file.

Output from WEATHER includes degree-days for each site, based on mean daily temperatures. To calculate degree-days, WEATHER subtracts a growth threshold temperature from each day's mean temperature, and sums the results over an entire year. Degree-day values were used in the species driver file, with the northern value as the minimum and the southern value as the maximum for each species. Following these are environmental tolerance parameters L, M, and N, which estimate tolerance to shade, drought, and nutrient deficiency, respectively. L and M are estimated on a scale from 1 to 5 (1=intolerant), and N is estimated on a scale from 1 to 3 (1=intolerant). None of these estimations is absolute; they are all ranks based upon each species' tolerance relative to the others'.

Once initial values were derived for each input file parameter, the model was run. ZELIG's main program produces five output files from which the results of the simulation can be determined. Output files include a print file, a log file, a tracer file, a punch file, and a profile of the leaf area index (LAI); see Appendix D for examples. The punch file summarizes ecological data for each 100-m^2 plot in the simulation. Represented variables in the punch file are year (kyr), row (kr), column (kc), soil type (ksol= msol[kr,kc]), density, biomass (mg/ha), basal area, (m^2/ ha^2), cumulative leaf area index (m^2/m^2), maximum canopy height (m), size class distribution (stems/ha, in 20 10-cm size classes), and basal area per species. This summary of per-plot data allows the investigator to compare variability among plots and to "illustrate stand attributes on a plot-by-plot basis" (Urban, 1993). The LAI profile breaks down the LAI by plot, and gives a separate value for each row, column, and canopy height on the model's grid. This profile may be processed and represented in graphical form to produce a detailed picture of the LAI by plot.

For the purposes of this paper, however, the print, log, and tracer files are more important than the other two. The print file contains information on stand structure and species composition for the forest as a whole, and prints it at user-specified time intervals. It begins with a review of the site and species input parameters. Then, at the end of each print interval (e.g. years 100, 200, etc. for a 100-year print interval), the file displays the stand structure by species, in stems per hectare in each of twenty 10-cm size classes. Totals for all species are also given. Species composition is summarized in a table listing density, relative density, basal area, relative basal area, importance value, and frequency. For ZELIG, the importance value is the arithmetic mean of relative density and relative basal area. Finally, for each print interval, several stand aggregates are listed: total density, total basal area, mean dbh, total woody biomass, mean LAI, and mean canopy height.

Print file data are important for determining how closely the simulation matches results from Barry and Kroll’s study of the actual forest. Also important to the analysis of the results of each run are the log and tracer files. The log file begins with a summary of site and climate conditions. It then gives reports the number of trees dying during the simulation, by size class. One interesting feature of this table is the division of dead trees into categories representing age-related mortality and stress-related mortality. Another table gives the growth status of each individual tree in one representative plot on the model’s grid. This table lists the species, dbh, and height of each tree, followed by a series of growth multipliers. Multipliers represent available light, soil moisture, soil fertility, and degree-days, and determine how much of each tree's growth potential it was able to achieve. This information proved to be very important to this study, because limiting environmental factors in the site could be identified and corrected for. Tables summarizing regeneration and light profile throughout the plot complete the log file. Since these factors did not influence the results of the model for this study, these tables were of limited importance to the analysis.

The tracer file consists of "a condensed stand-level output file which is designed to be ported directly to a graphics package, to illustrate the temporal dynamics of the simulated stand (Urban, 1992)." Included in this file are year, density, biomass, standard deviation o biomass, total basal area, mean LAI, mean canopy height, and basal area per species. These values are printed at user-determined time intervals within the simulation. Tracer file data were used to determine whether values such as basal area and total biomass exhibited oscillatory behavior over time, and whether values such as the leaf area index were typical for a southern bottomland forest.

The procedure of the ZELIG modeling experiment consisted of running the model using the best estimates for the parameters of each input file discussed above. Output files, particularly the print, log, and tracer files, were examined and evaluated. Then parameters in either the site or species driver files were altered experimentally, with the hope of achieving results closer to the actual field study. Details of these experiments, with their results, are presented in the next section.

Results

As stated above, the initial model run was made using parameter estimates based on forestry literature, allometric calculations in Splus, and some ZELIG default values. It was expected that the importance value results of this run would not match the Barry and Kroll study, and they did not. Table 12 shows the change in importance values over the simulation period of 500 years. What was not expected was that the trees would exhibit lack of growth even at 300-500 years. See Figures 6 and 7 for diameter class and average canopy height values, respectively. Manipulation of the species parameters brought the species composition results closer to the Barry study, but did not improve tree growth. Inspection of the log file showed the lack of growth to be the consequence of water stress. In most individual cases, the multiplier for soil moisture was at or near zero, resulting in little or no tree growth for the time interval shown in the file. To correct this problem, the depth of each soil layer was increased to retain more water within the root zone.

Table 12. Change in Importance Values for Each Species Over Simulation Period

	Yr 50	Yr 100	Yr 150	Yr 200	Yr 250	Yr 300	Yr 350	Yr 400	Yr 450	Yr 500
Species	**Importance Value**									
Green Ash	42.21	58.03	33.29	53.33	21.48	45.79	32.15	30.67	50.55	36.47
Cedar Elm	0.62	5.37	4.87	2.22	4.02	0	0.53	7.1	0	0.23
Hackberry	0.59	1.71	7.87	7.55	9.79	0	1.84	10.41	29.47	0.47
Bur Oak	56.58	34.89	53.74	36.89	64.15	54.21	65.48	51.82	19.98	62.83
Pecan	0	0	0.23	0	0.56	0	0	0	0	0

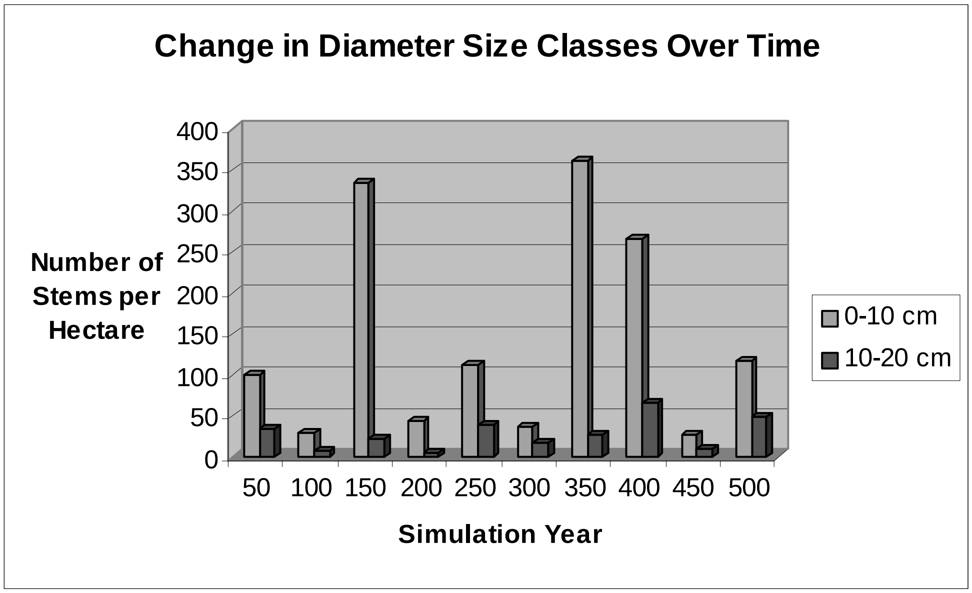


Figure 6. Diameter size classes over simulation period.

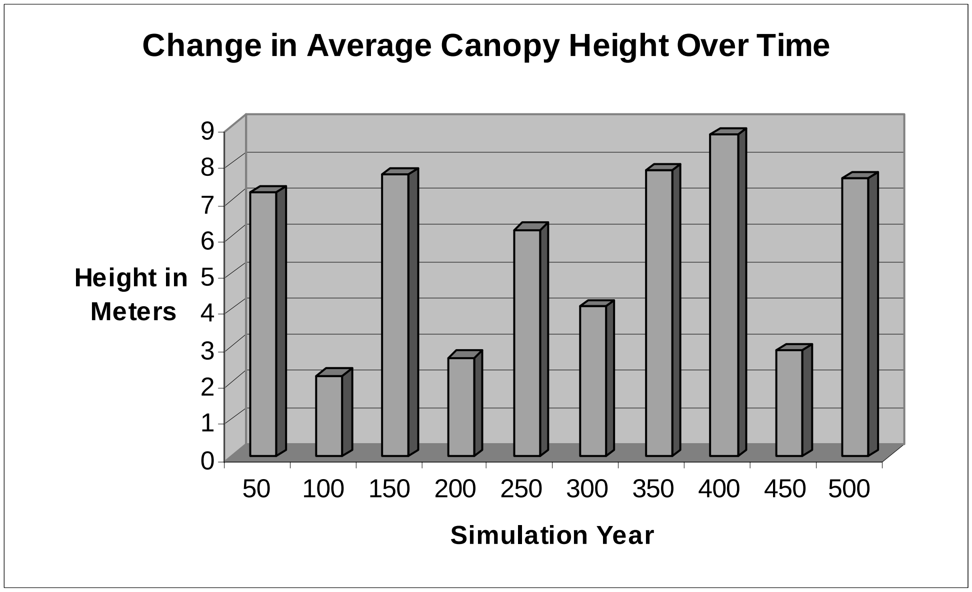


Figure 7. Average canopy heights over simulation period.

The soil depth parameters in the site driver file were then increased from 10 cm to 12 cm, and again to 15 cm. This increased the trees' diameters somewhat, but they remained far lower than actual tree diameters for the Greenbelt forest. Again, the log file showed that the problem was still one of water stress. Further manipulation of species parameters, including increasing drought tolerance to the maximum value for all species, did not improve the situation. In fact, this particular experiment altered the species' abilities to compete with one another, which resulted in unacceptable changes in the species composition of the forest. Giving Bur Oak a drought tolerance of 5 in every case gave it superior competitive advantage, and allowed it to dominate the forest.

Inspection of graphs of the tracer file data at this point also showed oscillatory behavior in biomass, standard deviation of biomass, total basal area, and basal area per species over time. To correct the tree size problem as well as this behavior,

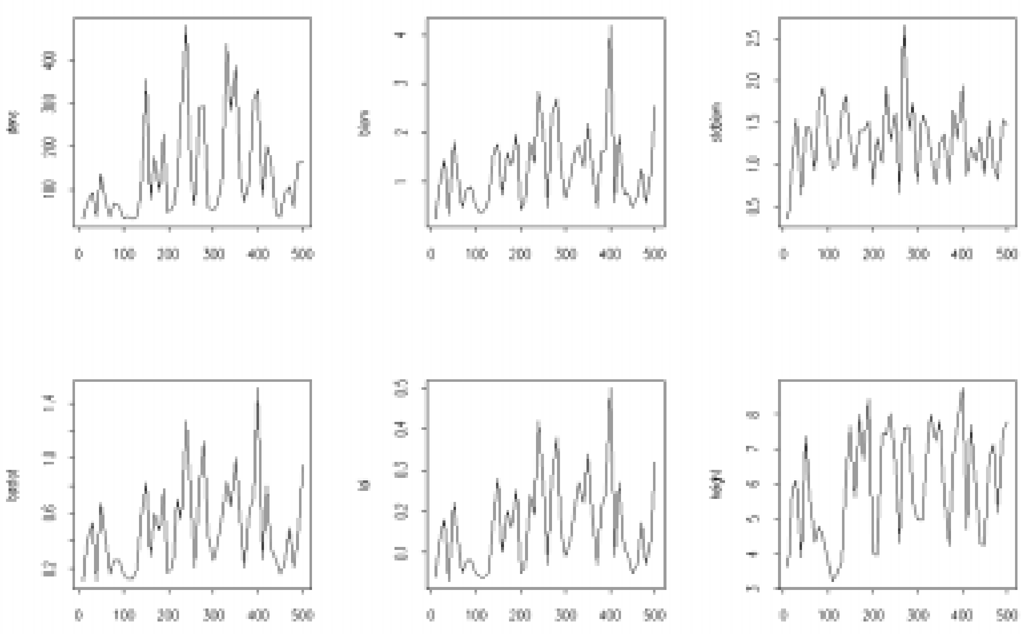


Figure 8 Tracer file graphs as displayed in Splus. The curves shown are, from left to right and top to bottom, density, total biomass, standard deviation of biomass, total basal area, leaf area index, and average canopy height.

precipitation values and their standard deviations were doubled experimentally. While this did result in a dramatic increase in tree size, some of the oscillatory behavior in the tracer file graphs remained. The standard deviations of the precipitation values were restored to their previous levels, but the actual values remained doubled. This produced the result of somewhat smoother tracer file curves while maintaining the gains in tree size. Model runs were then made with different precipitation levels, increasing at 10% increments, from the actual precipitation data to double the actual precipitation values. Standard deviations were left at the actual levels for each run. This was done in order to discover at what level the oscillatory behavior of the tracer file values would begin to smooth out. Results showed that oscillations decreased satisfactorily at approximately 180% of actual precipitation values; this result became the guideline for modification of the drought tolerance parameter in the species file.

Alteration of empirical climate data achieved the goal of raising soil moisture to levels at which tree growth could occur. However, this was an unacceptable means of accomplishing this goal. The next experiment was to change the drought tolerance function so that the species' drought tolerance parameters would effectively be increased tenfold. This maintained the positive gains in tree growth achieved by increasing precipitation values. Precipitation values were returned to the actual values for the Greenbelt site. Further experimentation with non-integer drought tolerance parameter values also increased the resolution of that parameter, which in turn led to the ability to fine-tune the species' competitive advantage, relative to one another. Examination of the ZELIG manual revealed that the species input file would accept a two-digit value for the drought tolerance parameter. Thus it became apparent that the tenfold increase in drought tolerance, as well as the finer resolution, could be achieved simply by choosing values between approximately 10 and 60 for that parameter. The drought tolerance function was returned to its original state, and the drought tolerance parameters for all species were experimentally increased by 10. Positive results were maintained.

Finally, to achieve the results obtained using the 180% precipitation levels, the drought tolerance parameters for all species were increased over their original levels (prior to the tenfold increase) proportionally to the decrease in the number of dry days from the original precipitation values to the increased ones. This was accomplished by averaging the number of dry days for all soil layers over the entire run of the model for each precipitation level. The average for the original precipitation run was divided by the average for the 180% precipitation run, resulting in a ninefold decrease in dry days for the 180% precipitation run. All species' drought tolerance parameters were then increased ninefold over their original levels, which achieved results in the tracer file similar to the 180% precipitation runs. Other species parameters were then fine-tuned to achieve the desired importance values and successional order. Final results of the drought tolerance alteration experiment can be seen in Table 13 and Figures 9 through 11.

Table 13. Change in Importance Values for Each Species Over Simulation Period

	Yr 50	Yr 100	Yr 150	Yr 200	Yr 250	Yr 300	Yr 350	Yr 400	Yr 450	Yr 500
Species	**Importance Value**									
Green Ash	36.34	25.94	13.44	11.02	14.41	11.71	11.45	12.81	10.63	13.71
Cedar Elm	17.49	21.74	33.12	32.38	22.95	26.19	33.43	26.77	32.58	28.21
Hackberry	15.19	24.22	30.75	39.19	49.49	53.91	49.86	56.28	53.21	54.51
Bur Oak	5.31	5.44	5.73	6.31	6.04	4.58	3.03	3.47	2.69	1.67
Pecan	25.67	22.66	16.97	11.09	7.1	3.62	2.22	0.67	0.88	1.91

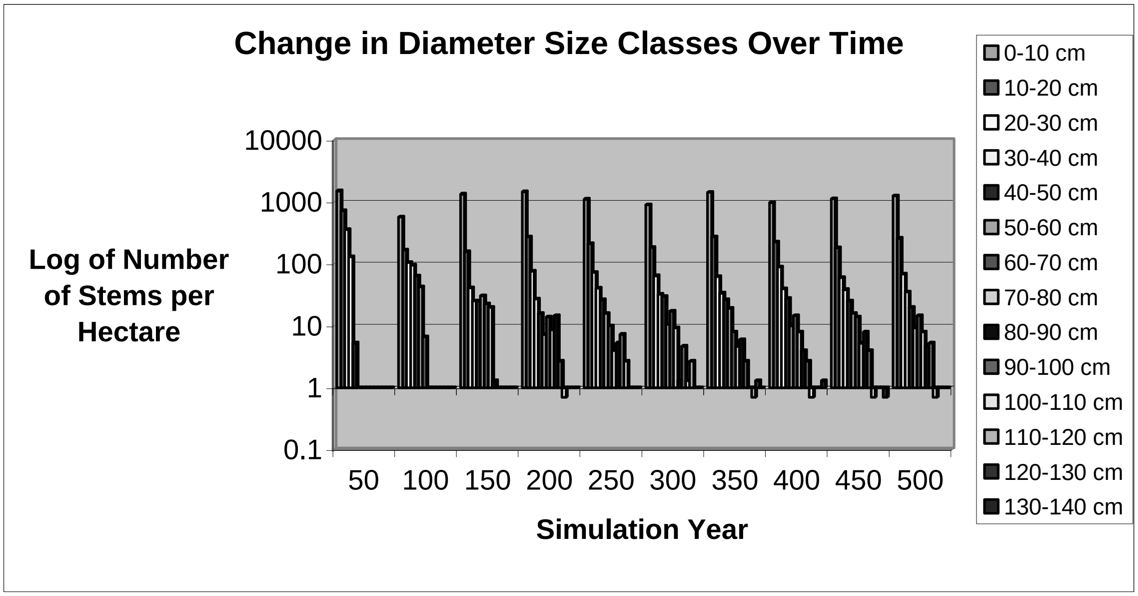


Figure 9. Change in diameter size classes over simulation run. Note the difference in the number of size classes, compared to original run (Figure 7).

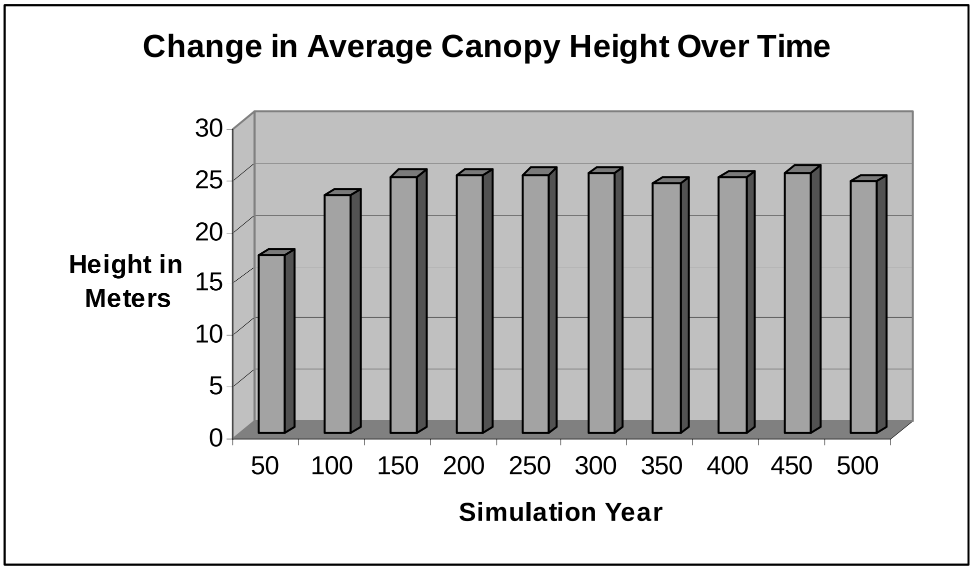


Figure 10. Change in average canopy height over simulation run. Note the difference from the original run (Figure 8).

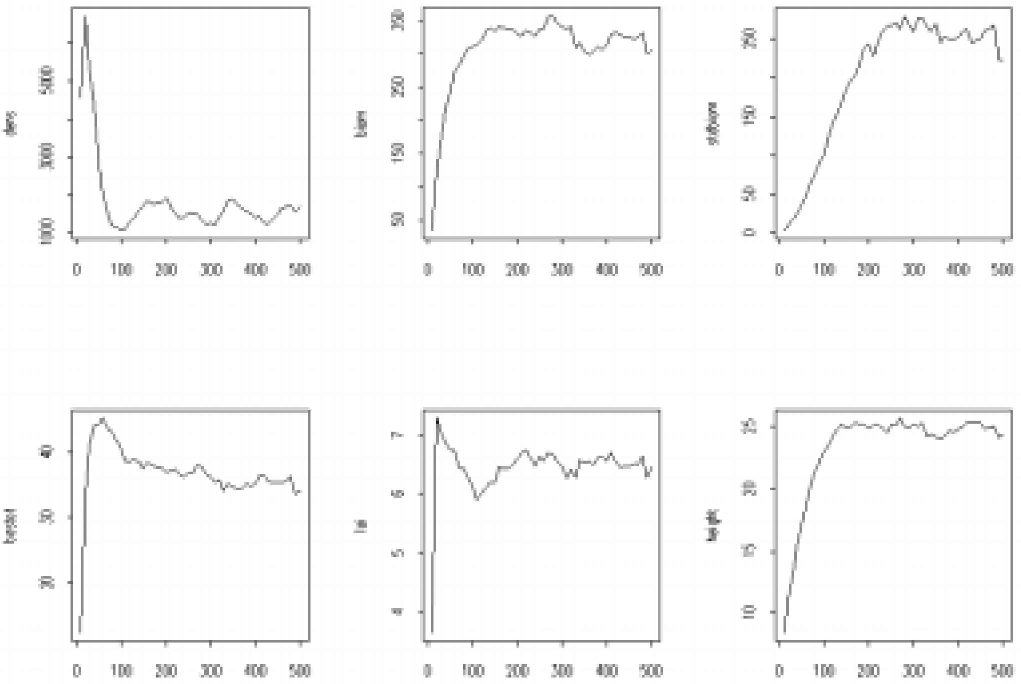


Figure 11. Tracer file graphs for final ZELIG run. Note that the oscillatory behavior is almost gone, although most curves retain a drop at around year 300.

The reason for this drop was never discovered. The curves displayed are density, total biomass, standard deviation of biomass, total basal area, leaf area index, and average canopy height.

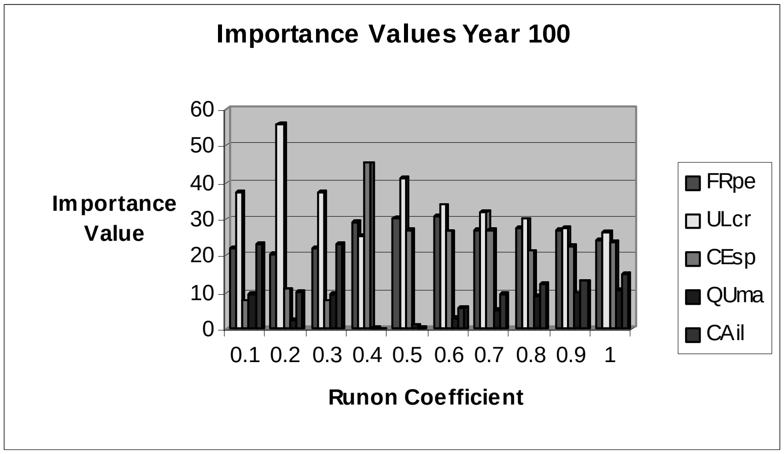
Although a better choice than changing empirical data such as precipitation values, altering the drought tolerance parameter to such a degree is still an undesirable method of adapting the ZELIG model to bottomland conditions because it changes a modeled biological characteristic of the tree species rather than an aspect of the model itself. Increasing the drought tolerance parameter to a level approximately ten times its intended value simulates a scenario in which trees thrive on much less water than they actually need. Therefore, another experiment was developed, in which the soil moisture was increased by adapting the model itself, rather than altering species parameters.

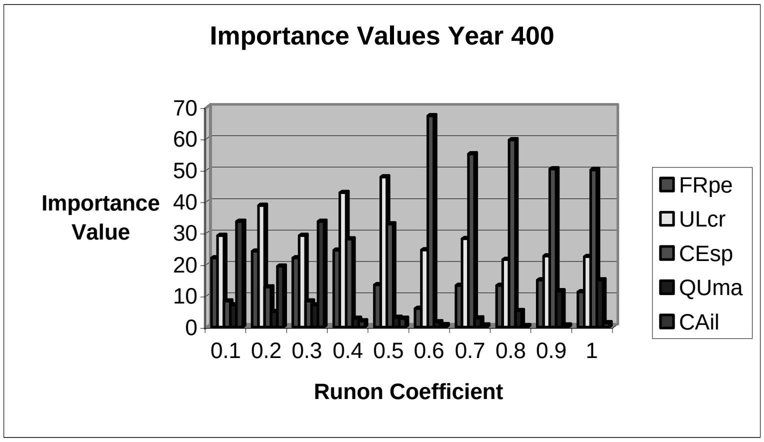
One disadvantage of the ZELIG model is that it does not simulate surface water runoff or pooling. The only function that allows for any water accumulation on the surface is the function that builds the snowpack. Since this function is temperature-dependent as well as precipitation-dependent, and since the Ray Roberts Greenbelt site is so warm, the simulations in this project never showed a snowpack. However, an experiment was developed whereby the snowpack function was adapted to simulate water running onto the plots in the simulated forest. A feature such as this was deemed to be reasonable, since river bottoms are low-lying areas, and water characteristically collects in them via flooding from the river or runoff from higher terraces and uplands nearby.

For this experiment, the part of the snowpack function related to temperature was bypassed, and the snowpack was simply set to a percentage of the precipitation, expressed as a runon coefficient written into the site driver file. The initial experimental value for the runon coefficient was 0.10, or ten percent of precipitation. No attempt was made to add a pooling function; all the water added to the surface as runon was treated as soaking directly into the top layer of soil. Upon entering the top layer of soil, it was subject to the normal surface evaporation and evapotranspiration functions of the model. ZELIG uses the Priestley-Taylor equations to calculate potential evapotranspiration.

Water moving through the soil layers is simulated as a “tipping bucket” process; as one layer becomes saturated, excess water enters the next layer down. Any excess water remaining in the bottom soil layer is lost to the water table, and is written to the log output file as cumulative runoff. Prior to the current experiment, the log file showed no runoff in any simulation interval, except for intervals of unusually high precipitation. Adding another 10 percent of water to the simulation was expected to increase deep runoff, but it did not. Tree growth, as shown in the print file, was improved over the original run, but not very much; trees still did not exceed 20 cm dbh or 9 m in average canopy height in any interval. Tree dbh did not exceed 20 cm until the runon coefficient was increased to 0.4. At this point, green ash and cedar elm reached a maximum of 50-60 cm at year 250, and hackberry reached a maximum of 80-90 cm at year 350. Thus it appeared that a runon coefficient threshold was reached between 0.3 and 0.4.

Further runs were made, increasing the runon coefficient in 0.1 increments, to a maximum of 1.0. The runon coefficient of 1.0 mimicked the doubling of the precipitation levels of the first experiment, except instead of manipulating the actual precipitation data, the change was engineered by introducing water from a hypothetical surface source, e.g. flooding from the river or surface runoff from higher elevations. The run that achieved importance values that most closely matched the Barry and Kroll study results was the run with a runon coefficient of 0.7, around year 400. Comparisons of importance values for each species with different runon coefficients at simulation years 100, 400, and 500 are shown in Figure 12. These particular years were chosen to show the forest at an immature stage, at the year containing optimum species composition results, and at the final (climax) stage. Appendix E contains graphs of the change in importance values over the entire run for several different runon coefficients. It also contains tracer file graphs for the same coefficients.





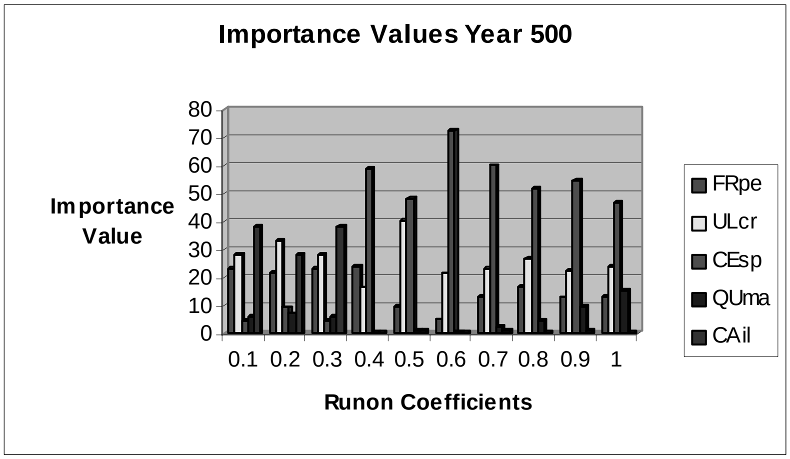
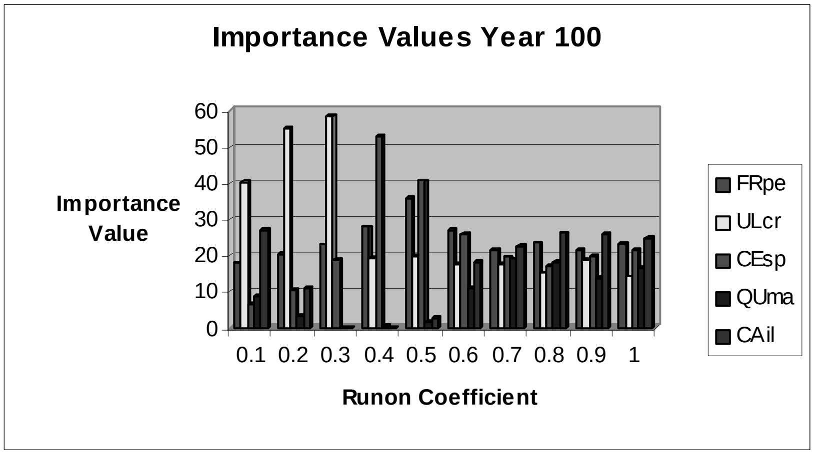
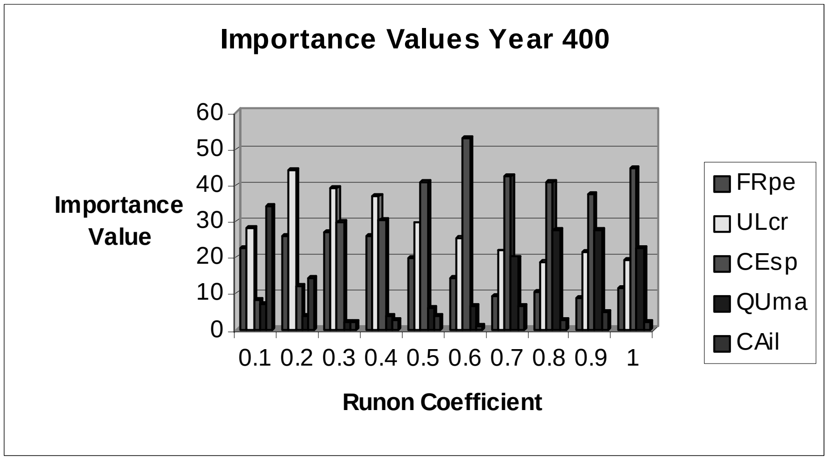


Figure 12. Comparison of importance values for significant simulation years, runon coefficient experiment. Note: FRpe = Green Ash (*Fraxinus pennsylvanica*), ULcr = Cedar Elm (*Ulmus crassifolia*), CEsp = Hackberry (*Celtis* spp.), QUma = Bur Oak (*Quercus macrocarpa*), and CAil = Pecan (*Carya illinoensis*).

Since the runon coefficient had to be raised to unrealistically high values to achieve the desired tree growth, one final experiment was attempted. In the ZELIG model, water trickles through the soil column at a fixed rate, with no possibility of pooling on the surface. Any excess is lost to the water table from the bottom soil layer. For this experiment, the snowpack function was further modified to allow water to infiltrate at a variable rate dependent upon the amount of water within the soil column. As the soil column developed a water deficit, water from the surface infiltrated the top layer in a proportional amount. If the deficit exceeded the available surface water, the entire pool infiltrated the top layer, and percolated through the column in the usual manner.

This alteration to the snowpack function stopped excess water from being lost to the water table, and made some difference in the development of the forest. Although some growth of trees beyond 20 cm dbh occurred at a runon coefficient of 0.3, particularly in the hackberries, consistent growth similar to the previous experiment did not occur until the runon coefficient was raised to 0.4. Optimum results were achieved at a lower runon coefficient, however. Species composition results closest to the Barry and Kroll study occurred with a runon coefficient of 0.6, year 400. Figure 13 shows a comparison of importance values at simulation years 100, 400, and 500 as above. Graphs of importance values for entire runs at several different runon coefficients are shown in Appendix F.





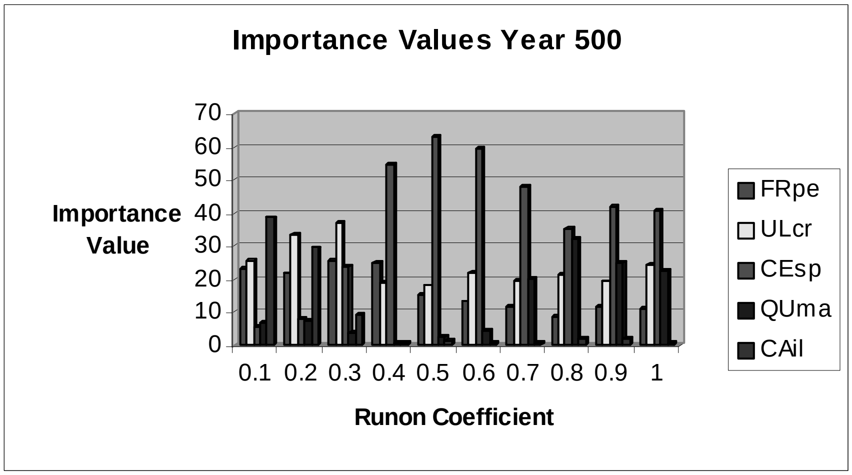


Figure 13. Comparison of importance values for significant simulation years, pond experiment. Note: FRpe = Green Ash (*Fraxinus pennsylvanica*), ULcr = Cedar Elm (*Ulmus crassifolia*), CEsp = Hackberry (*Celtis* spp.), QUma = Bur Oak (*Quercus macrocarpa*), and CAil = Pecan (*Carya illinoensis*).

The goal of this study was to adapt the ZELIG model to a southern bottomland hardwood forest. The first experiment, artificially increasing the amount of precipitation at the Greenbelt site, demonstrated that increasing the available soil moisture was necessary to achieve the actual tree growth. In the absence of a source of additional soil moisture, the second experiment of raising each species' drought tolerance parameter could simulate the same results. However, since both of these methods were artificial, ways of altering the model to account for all available water sources were sought.

The last two experiments were focused on simulating surface water running onto the low-lying bottomland forest plots. In the third experiment, a runon coefficient was added via the snowpack function in the model. A pooling adjustment was made to the same function in order to slow the rate of water infiltration through the soil layer and stop the loss of excess water to deep percolation in the final experiment. Both of these experiments were moderately successful, but the runon coefficient had to be set unrealistically high in order to achieve results close to observed tree growth. Suggestions for further experimentation with the ZELIG model to simulate bottomland hardwood forests are presented below.

Discussion

In the course of this study, the ZELIG model was noted to be incompatible with the simulation of a bottomland hardwood forest because of the inability to simulate a nearby water source. Most of the experimentation, as presented in the previous section, was concerned with accommodating this problem. In order to avoid the artificial manipulation of actual precipitation data and biological parameters, some simple modifications to the model's code were made to try to simulate an additional source of soil moisture associated with riparian bottomland systems. With further experimentation, other sources of soil moisture could be simulated, and the combination of these modifications could allow the researcher to adjust the model to accommodate a soil moisture gradient from the riverbank to the upland terrace.

Further attempts to refine the runon coefficient should be made. One way to do this could be to tie the changes in runon coefficient to the topographical profile of the forest being simulated. For more general simulations, the coefficient could be tied to a general riparian topological profile, such as those shown by Forman (1995).

In addition to simulating the addition of surface runon, it may be possible to develop a function or subroutine to simulate access to the water table as a function of proximity to the river. The soil in the Ray Roberts Greenbelt contains a large percentage of clay-sized particles (NRCS, 1980). In silty and clayey soils, water often percolates upward from the water table via capillary action (McCuen, 1998). It may be that the trees of the Greenbelt are able to tap water from this capillary fringe. Access to groundwater would certainly increase soil moisture over what is apparently available from precipitation alone. To test this idea, field data could be collected from the Greenbelt site. Walking a transect perpendicular to the Elm Fork, one could test the soil moisture and water table level at regular intervals from the riverbank to the upland terrace. These field data could then be incorporated into this new function or subroutine, so that water table access could reflect actual site conditions.

Coupled with both of the above suggestions could be an additional function to simulate wet days. A flood tolerance parameter would be added to the species file for use with this function. During wet periods, species that are more flood-tolerant, such as Green Ash, would be favored. If this parameter and one of the above suggestions for retaining soil moisture were to be applied as a function of distance to the river, or as a function of topography, the result could be a much patchier forest that more closely resembles a natural forest. As Barry and Kroll (1999) showed, the remnant bottomland forest of the Ray Roberts Greenbelt is highly patchy.

After the soil moisture problem, the next most difficult aspect of the model, with regard to this study, was the fact that shade tolerance is treated as the absolute determining factor in the order of succession. This created a conflict between the literature sources. In particular, Bur Oak is listed as not being especially shade tolerant (USDA, 1999). However, ecology literature suggests that the oak-dominated forest is the climax condition for southern bottomland hardwoods (Hodges, 1997). For this study, a compromise with regard to shade tolerance was reached, so that the successional order would reflect that in the ecological literature, and so that the forest would approximate the importance values found by Barry and Kroll (1999) at some point in the simulation between 300 and 500 years. It might be possible to improve this situation by adopting a similar approach to the shade tolerance parameter that was applied to the drought tolerance parameter in this study. That is, increase the magnitude and resolution of the possible values. Further study and experimentation would be needed to assess the validity of this approach.

Finally, the length of the growing season reported by in the log file was an item of interest in this study, although it was not known to have had any impact on the results of the simulations. In many of the runs, the growing season was reported to be 365 days, due to the warm climate at the Greenbelt site. While it is true that the temperature remains high enough to allow growth throughout the year, it is also true that the forest being simulated in this study is a deciduous one. It would be interesting to find out whether the model simulates a period of dormancy for deciduous trees, or whether the trees continue growing throughout the simulation's growing period. Since that was a minor issue with regard to this study, it was not pursued.

CONCLUSION

To recapitulate, the objectives for this study were to present the need for preserving bottomland hardwood forests in north central Texas; to characterize the Lake Ray Roberts Greenbelt forest with regard to its physical habitat characteristics; and to calibrate the ZELIG model for that particular bottomland hardwood forest.

Chapter One achieved the first objective by presenting a basic description of southern bottomland hardwood forest ecology. Many of the ecological benefits that these ecosystems provide were listed as well, and the potential economic value of said benefits was mentioned briefly. An overview of the history of efforts to preserve bottomland forests in Texas, as well as some historic reasons for doing so, concluded the first chapter.

Chapter Two reported on the phytosocial study of the Ray Roberts Greenbelt Corridor Study. This area fell entirely within the riparian zone around the Elm Fork of the Trinity River, between the Ray Roberts and Lewisville reservoirs. Most of the Greenbelt land would historically have been bottomland hardwood forest, but has been used for other purposes, such as farming and grazing at various times since European settlement. A detailed phytosocial survey of the species composition and stand characteristics of the corridor and patch areas of the Greenbelt forest met the second study objective. Little difference was found between corridor and patch areas with regard to physical habitat characteristics such as percent similarity of species, complexity indices, and canopy height diversity. Thus, it was concluded that the corridors provide habitat similar to that of the patches, and can serve as vital connectors between larger areas of habitat. Recommendations regarding optimum width of forest corridors were presented, based upon a specific habitat goal (protecting forest interior bird species), and based upon more general goals (optimizing movement within the forest of a variety of species).

Chapter Three described the process by which the ZELIG gap model was calibrated to simulate the Ray Roberts Greenbelt forest. First, a phytosocial study of the largest and most pristine remnant bottomland forest within the Greenbelt was summarized. Importance value results from this study were used to calibrate the model with regard to species composition. Problems with the low soil moisture factor were encountered during this process. Three experiments undertaken to solve them were also presented: raising the species' drought tolerance parameters, modifying the snowpack function to simulate water runon, and simulating water pooling to stop loss of excess water to deep percolation. A discussion of possibilities for further study of the ZELIG model and bottomland hardwood forests ended the chapter.

The bottomland hardwood forest, an ecosystem that provides essential ecological benefits, is disappearing at an alarming rate due to logging, water impoundment, development, and other factors. Detailed field studies can help researchers to understand and evaluate the remaining areas of mature bottomland forest. In the absence of the time and resources necessary to conduct such studies, however, computer simulations may be able to provide needed information. This project was an attempt to understand the bottomland hardwood forest in north central Texas through its ecology and history as well as through field study and computer simulation. Perhaps as society begins to know these ecosystems in broad contexts, it may begin to value them more highly as intact systems than for their saleable goods.

APPENDIX A

SPECIES OF THE LAKE RAY ROBERTS GREENBELT

Trees

Common Name	Scientific Name
Box Elder	*Acer negundo*
Chittamwood	*Bumelia lanuginosa*
Pecan	*Carya illinoensis*
Sugar Hackberry	*Celtis laevigata*
American Hackberry	*Celtis occidentalis*
Hawthorn	*Crataegus* spp.
Green ash	*Fraxinus pennsylvanicus*
Honey locust	*Gleditsia triacanthos*
Black walnut	*Juglans nigra*
Bois d'arc	*Maclura pomifera*
Red Mulberry	*Morus rubra*
Sycamore	*Platanus occidentalis*
Cottonwood	*Populus deltoides*
Bur oak	*Quercus macrocarpa*
Blackjack oak	*Quercus marilandica*
Shumard oak	*Quercus shumardii*
Post oak	*Quercus stellata*
Black willow	*Salix nigra*
Wild Chinaberry	*Sapindus* spp.
Cedar elm	*Ulmus crassifolia*
Slippery elm	*Ulmus rubra*
American elm	*Umus americana*

Birds

Common Name	Scientific Name
Red-winged Blackbird	*Agelaius phoeniceus*
Ruby-throat Hummingbird	*Archilochus colubris*
Upland Sandpiper	*Bartramia longicauda*
Broad-winged Hawk	*Buteo platytperus*
American Goldfinch	*Carduelis tristis*
House Finch	*Carpodacus mexicanus*
Great Egret	*Casmerodius albus*
Belted Kingfisher	*Ceryle alcyon*
Inca Dove	*Columbina inca*
Eastern Wood Pewee	*Contopus pertinax*
Yellow-rumped Warbler	*Dendroica coronata*
Yellow Warbler	*Dendroica petechia*
Barn Swallow	*Hirundo rustica*
Dark-eyed Junco	*Junco hyemalis*
Lincoln's Sparrow	*Melospiza lincolnii*
Brown-headed Cowbirds	*Molothrus ater*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Hairy Woodpecker	*Picoides villosus*
European Starling	*Sturnus vulgaris*
Bewick's Wren	*Thryomanes bewickii*
Carolina Wren	*Thryothorus ludovicianus*
Eastern Kingbird	*Tyrannus tyrannus*
Canada Warbler	*Wilsonia canadensis*
Stellar's Flycatcher	

Mammals

Common Name	Scientific Name
Beaver	*Castor canadensis*
Nine-banded Armadillo	*Dasypus novemcinctus*
Opossum	*Didelphis marsupialis*
Bobcat	*Lynx rufus*
Striped Skunk	*Mephitis mephitis*
White-tailed Deer	*Odocoileus virginanus*
Raccoon	*Procyon lotor*
Coyote	*Canis latrans*
Eastern Conttontail	*Sylvilagus floridanus*

(adapted from Barry et al., 2000)

APPENDIX B

RAY ROBERTS GREENBELT PHYTOSOCIAL STUDY RAW DATA

Avian Plot Raw Tree Data

Plot	Species	Species Code	dbh (cm)	Basal area (cm^2)	Sum of Basal area	Total Trees	Canopy Layers	Species Richness	Complexity Index
1 E	Hackberry	4	95	7088.218425	8335.823407	3	5	2	2.500747
	Hackberry	4	13.5	143.1388153					
	Box Elder	14	37.5	1104.466167					
2 E	Pecan	17	14	153.93804	2816.045115	11	4	3	3.717180
	Pecan	17	17.5	240.5281875					
	Pecan	17	11.5	103.8689071					
	Pecan	17	13	132.7322896					
	Pecan	17	12	113.0973355					
	Pecan	17	15.5	188.6919088					
	Pecan	17	22.5	397.6078202					
	Pecan	17	13	132.7322896					
	Cedar Elm	2	22	380.1327111					
	Cedar Elm	2	32.5	829.5768101					
	Black Walnut	8	13.5	143.1388153					
3 W	Hackberry	4	37.5	1104.466167	11476.63066	7	5	4	16.067283
	Hackberry	4	47	1734.944543					
	Hackberry	4	32	804.2477193					
	Hackberry	4	39	1194.590607					
	Bois d'Arc	3	22	380.1327111					
	American Elm	18	76.5	4596.346402					
	snag	5	46	1661.902514					
4 W	Hackberry	4	28	615.7521601	3094.665113	6	4	2	1.485439
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	14	153.93804					
	Hackberry	4	13	132.7322896					
	Green Ash	1	39	1194.590607					
	Green Ash	1	20	314.1592654					
5 E	Slippery Elm	12	23.5	433.7361357	4802.51342	5	5	3	3.601885
	Slippery Elm	12	16.5	213.82465					
	Slippery Elm	12	47.5	1772.054606					
	Hackberry	4	53	2206.183441					
	Red Mulberry	7	15	176.7145868					
6 W	Hackberry	4	28	615.7521601	4840.80158	4	4	2	1.549057
	Hackberry	4	43.5	1486.169675					
	Hackberry	4	41	1320.254313					
	American Elm	18	42.5	1418.625433					
7 W	Red Mulberry	7	22.5	397.6078202	8666.083335	5	5	4	8.666083
	Hackberry	4	52.5	2164.753688					
	snag	5	19	283.528737					
	snag	5	30.5	730.6166415					
	Bur Oak	9	80.5	5089.576448					
8 E	Pecan	17	34.5	934.820164	2940.923423	4	4	4	1.882191
	American Elm	18	15.5	188.6919088					
	Hackberry	4	45	1590.431281					
	snag	5	17	226.9800692					
9 E	Hackberry	4	36.5	1046.346703	6925.051956	4	5	2	2.770021
	Hackberry	4	43	1452.201204					
	Hackberry	4	50	1963.495408					
	Green Ash	1	56	2463.00864					
10 W	Cottonwood	19	79	4901.669938	8043.85164	8	5	3	9.652622
	Hackberry	4	23	415.4756284					
	Hackberry	4	24.5	471.4352476					
	Hackberry	4	19.5	298.6476516					
	Hackberry	4	16	201.0619298					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	35	962.1127502					
	snag	5	30	706.8583471					
11 E	Box Elder	14	23.5	433.7361357	8422.806254	8	4	4	10.781192
	Slippery Elm	12	18	254.4690049					
	Slippery Elm	12	12.5	122.718463					
	Slippery Elm	12	43.5	1486.169675					
	snag	5	14	153.93804					
	Hackberry	4	18.5	268.8025214					
	Hackberry	4	61	2922.466566					

	Hackberry	4	59.5	2780.505848					
12 E	Hackberry	4	19.5	298.6476516	5306.93539	7	4	2	2.971884
	Hackberry	4	19.5	298.6476516					
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	44.5	1555.284713					
	Hackberry	4	13	132.7322896					
	Hackberry	4	24	452.3893421					
	Green Ash	1	49	1885.74099					
13 E	Cedar Elm	2	23	415.4756284	3881.045024	12	5	4	9.314508
	Cedar Elm	2	19	283.528737					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	14	153.93804					
	Hackberry	4	12.5	122.718463					
	Hackberry	4	41.5	1352.651987					
	Hackberry	4	12	113.0973355					
	Hackberry	4	13.5	143.1388153					
	Hackberry	4	12.5	122.718463					
	Green Ash	1	23.5	433.7361357					
	Green Ash	1	24	452.3893421					
	snag	5	16	201.0619298					
14 W	Green Ash	1	11.5	103.8689071	103.8689071	1	3	1	0.003116
15 E	Green Ash	1	12.5	122.718463	7301.650376	5	5	5	9.127063
	Hackberry	4	37	1075.210086					
	Shumard Oak	13	59.5	2780.505848					
	Bur Oak	9	41	1320.254313					
	Cedar Elm	2	50.5	2002.961666					
16 E	Hackberry	4	52	2123.716634		3	5	3	3.285743
	Green Ash	1	54.5	2332.828895					
	snag	5	63	3117.245311					
17 E	Bois d'Arc	3	36	1017.87602	3283.357022	5	5	2	1.641679
	Bois d'Arc	3	26.5	551.5458602					
	Bois d'Arc	3	34	907.9202769					
	Bois d'Arc	3	26.5	551.5458602					
	snag	5	18	254.4690049					
18 E	Post Oak	20	14.5	165.1299639	762.2289176	4	4	3	0.365870
	Post Oak	20	10.5	86.59014751					
	Blackjack Oak	21	11	95.03317777					
	Cedar Elm	2	23	415.4756284					
19 E	Cedar Elm	2	46	1661.902514	7053.857255	4	4	1	1.128617
	Cedar Elm	2	48.5	1847.45283					
	Cedar Elm	2	48	1809.557368					
	Cedar Elm	2	47	1734.944543					
20 E	Cedar Elm	2	37.5	1104.466167	3824.496357	5	4	2	1.529799
	Hackberry	4	48	1809.557368					
	Hackberry	4	25	490.8738521					
	Hackberry	4	18	254.4690049					
	Hackberry	4	14.5	165.1299639					
21 E	Green Ash	1	33.5	881.4130889	9437.73703	6	5	3	8.493963
	Green Ash	1	65	3318.30724					
	Green Ash	1	19	283.528737					
	Pecan	17	12.5	122.718463					
	Hackberry	4	26	530.9291585					
	Hackberry	4	74	4300.840343					
22 E	Bur Oak	9	93	6792.908715	11883.85961	7	5	4	16.637403
	Hackberry	4	18.5	268.8025214					
	Hackberry	4	26.5	551.5458602					
	Hackberry	4	54.5	2332.828895					
	Hackberry	4	26.5	551.5458602					
	Pecan	17	26	530.9291585					
	snag	5	33	855.2985999					
23 W	Slippery Elm	12	20.5	330.0635782	16960.28064	5	5	3	12.720210
	Pecan	17	114	10207.03453					
	Pecan	17	74.5	4359.156156					
	Hackberry	4	18	254.4690049					
	Hackberry	4	48	1809.557368					
24 W	Hackberry	4	19	283.528737	4604.985782	4	4	4	2.947191
	Green Ash	1	39	1194.590607					
	snag	5	21	346.3605901					
	Slippery Elm	12	59.5	2780.505848					

25 E	Hackberry	4	21	346.3605901	15270.69284	10	5	3	22.906039
	Hackberry	4	39	1194.590607					
	Hackberry	4	57.5	2596.722678					
	Hackberry	4	22	380.1327111					
	snag	5	27.5	593.9573611					
	snag	5	71	3959.192142					
	snag	5	14.5	165.1299639					
	snag	5	24.5	471.4352476					
	Green Ash	1	73.5	4242.917228					
	Green Ash	1	41	1320.254313					
26 E	Box Elder	14	24.5	471.4352476	7278.28478	7	5	4	10.189599
	Box Elder	14	37	1075.210086					
	American Elm	18	30	706.8583471					
	American Elm	18	41.5	1352.651987					
	American Elm	18	38.5	1164.156428					
	Green Ash	1	29	660.5198554					
	Hackberry	4	48.5	1847.45283					
27 W	Hackberry	4	35	962.1127502	6312.441389	6	4	5	7.574930
	Hackberry	4	21	346.3605901					
	Green Ash	1	58	2642.079422					
	Cedar Elm	2	48	1809.557368					
	Red Mulberry	7	18.5	268.8025214					
	Bur Oak	9	19	283.528737					
28 E	Green Ash	1	27	572.5552611	5193.445355	9	3	4	5.608921
	Green Ash	1	24	452.3893421					
	Green Ash	1	28	615.7521601					
	Green Ash	1	47	1734.944543					
	Bur Oak	9	16	201.0619298					
	Hackberry	4	19.5	298.6476516					
	Hackberry	4	23	415.4756284					
	Box Elder	14	20.5	330.0635782					
	Box Elder	14	27	572.5552611					
29 W	Red Mulberry	7	11	95.03317777	4165.16281	4	5	3	2.499098
	Hackberry	4	10.5	86.59014751					
	American Elm	18	44	1520.530844					
	American Elm	18	56	2463.00864					
30 W	Green Ash	1	45	1590.431281	1723.16357	2	4	2	0.275706
	Box Elder	14	13	132.7322896					
31 E	snag	5	14.5	165.1299639	4956.058761	6	3	3	2.676272
	Cedar Elm	2	29	660.5198554					
	Cedar Elm	2	35.5	989.7980354					
	Cedar Elm	2	37.5	1104.466167					
	Cedar Elm	2	36.5	1046.346703					
	Chittamwood	6	35.5	989.7980354					
32 E	Hackberry	4	10	78.53981634	3637.767943	9	4	2	2.619193
	Hackberry	4	13	132.7322896					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	11	95.03317777					
	Hackberry	4	13.5	143.1388153					
	Cedar Elm	2	33	855.2985999					
	Cedar Elm	2	30	706.8583471					
	Cedar Elm	2	20	314.1592654					
	Cedar Elm	2	39.5	1225.417484					
33 E	Honey Locust	10	10.5	86.59014751	687.6160921	4	4	3	0.330056
	Honey Locust	10	16.5	213.82465					
	snag	5	13	132.7322896					
	Hackberry	4	18	254.4690049					
34 W	Bur Oak	9	50	1963.495408	7598.138182	6	5	5	11.397207
	Hackberry	4	50	1963.495408					
	Hackberry	4	65	3318.30724					
	snag	5	14	153.93804					
	American Elm	18	11.5	103.8689071					
	Box Elder	14	11	95.03317777					
35 W	Hackberry	4	34	907.9202769	6233.312524	6	4	4	5.983980
	Hackberry	4	33	855.2985999					
	Hackberry	4	32.5	829.5768101					
	American Elm	18	48	1809.557368					
	Green Ash	1	46.5	1698.227179					

	snag	5	13	132.7322896					
36 E	Green Ash	1	70	3848.451001	22207.32942	10	4	2	17.765864
	Green Ash	1	40	1256.637061					
	Green Ash	1	38	1134.114948					
	Green Ash	1	61	2922.466566					
	Green Ash	1	45	1590.431281					
	Green Ash	1	48	1809.557368					
	Green Ash	1	45	1590.431281					
	Green Ash	1	68	3631.681108					
	Green Ash	1	74	4300.840343					
	snag	5	12.5	122.718463					
37 W	snag	5	36	1017.87602	9029.133636	5	5	3	6.771850
	American Elm	18	10	78.53981634					
	American Elm	18	10	78.53981634					
	American Elm	18	10	78.53981634					
	Green Ash	1	99.5	7775.638167					
38 W	Hackberry	4	27.5	593.9573611	3350.901264	4	4	2	1.072288
	Hackberry	4	17.5	240.5281875					
	Hackberry	4	30	706.8583471					
	Cedar Elm	2	48	1809.557368					
39 W	Hackberry	4	23	415.4756284	5187.947568	10	4	4	8.300716
	Hackberry	4	26	530.9291585					
	Hackberry	4	14.5	165.1299639					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	22	380.1327111					
	snag	5	17	226.9800692					
	snag	5	12.5	122.718463					
	Cedar Elm	2	31.5	779.3113276					
	Cedar Elm	2	51.5	2083.072279					
	Bois d'Arc	3	22.5	397.6078202					
40 W	Green Ash	1	25.5	510.7051557	8143.793556	4	4	2	2.606014
	Green Ash	1	11	95.03317777					
	Green Ash	1	59	2733.971007					
	Hackberry	4	10.5	86.59014751					
41 W	Hackberry	4	14	153.93804	4830.591404	7	4	4	5.410262
	Cedar Elm	2	28	615.7521601					
	Cedar Elm	2	23.5	433.7361357					
	snag	5	13	132.7322896					
	snag	5	35	962.1127502					
	snag	5	55.5	2419.222693					
	Hawthorn	11	12	113.0973355					
Notes:	(Large snag is Bur Oak.)			0					
42 W	Cedar Elm	2	47	1734.944543	3984.128533	7	3	3	2.510001
	Cedar Elm	2	34.5	934.820164					
	Cedar Elm	2	26	530.9291585					
	snag	5	20.5	330.0635782					
	snag	5	14	153.93804					
	Hackberry	4	12.5	122.718463					
	Hackberry	4	15	176.7145868					
43 W	Green Ash	1	18.5	268.8025214	4440.444866	7	4	5	6.216623
	Green Ash	1	18	254.4690049					
	Green Ash	1	17.5	240.5281875					
	Hackberry	4	44.5	1555.284713					
	Honey Locust	10	21	346.3605901					
	Cedar Elm	2	12	113.0973355					
	Bur Oak	9	46	1661.902514					
44 E	Green Ash	1	31	754.767635	3804.861403	5	5	2	1.902431
	Green Ash	1	24	452.3893421					
	Green Ash	1	41	1320.254313					
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	27.5	593.9573611					
45 E	Cedar Elm	2	39.5	1225.417484	4025.950986	5	4	1	0.805190
	Cedar Elm	2	26.5	551.5458602					
	Cedar Elm	2	21.5	363.050301					
	Cedar Elm	2	43	1452.201204					
	Cedar Elm	2	23.5	433.7361357					
46 E	American Elm	18	41.5	1352.651987	5724.570863	4	5	3	3.434743
	snag	5	13.5	143.1388153					
	Hackberry	4	48	1809.557368					

	Hackberry	4	55.5	2419.222693					
47 E	Hackberry	4	31	754.767635	7731.85222	9	5	3	10.438000
	Hackberry	4	29	660.5198554					
	Hackberry	4	48	1809.557368					
	snag	5	46.5	1698.227179					
	snag	5	10	78.53981634					
	Cedar Elm	2	27	572.5552611					
	Cedar Elm	2	31	754.767635					
	Cedar Elm	2	18.5	268.8025214					
	Cedar Elm	2	38	1134.114948					
48 E	Hackberry	4	12	113.0973355	2502.671248	7	5	4	3.503740
	Hackberry	4	15	176.7145868					
	American Elm	18	14.5	165.1299639					
	American Elm	18	14	153.93804					
	American Elm	18	13	132.7322896					
	snag	5	44	1520.530844					
	Green Ash	1	17.5	240.5281875					
49 E	Green Ash	1	12.5	122.718463	2108.008671	12	5	5	6.324026
	Green Ash	1	11.5	103.8689071					
	snag	5	10	78.53981634					
	snag	5	13	132.7322896					
	snag	5	12	113.0973355					
	snag	5	13.5	143.1388153					
	snag	5	11	95.03317777					
	snag	5	25	490.8738521					
	American Elm	18	13	132.7322896					
	Box Elder	14	19.5	298.6476516					
	Box Elder	14	19	283.528737					
	Hackberry	4	12	113.0973355					
50 E	Green Ash	1	44	1520.530844	10901.52286	4	5	3	6.540914
	Green Ash	1	59	2733.971007					
	American Elm	18	13.5	143.1388153					
	snag	5	91	6503.882191					
51 E	Green Ash	1	62	3019.07054	10200.9477	6	5	4	12.241137
	Green Ash	1	76.5	4596.346402					
	Green Ash	1	44	1520.530844					
	American Elm	18	26	530.9291585					
	snag	5	22	380.1327111					
	Hackberry	4	14	153.93804					
52 E	Hackberry	4	16	201.0619298	12468.98124	6	5	4	14.962777
	Hackberry	4	17	226.9800692					
	Green Ash	1	38.5	1164.156428					
	Green Ash	1	38.5	1164.156428					
	Bois d'Arc	3	12.5	122.718463					
	snag	5	110.5	9589.907925					
53 E	Hackberry	4	36.5	1046.346703	4580.245739	3	5	3	2.061111
	Green Ash	1	61	2922.466566					
	American Elm	18	17	226.9800692					
54 W	Hackberry	4	13	132.7322896	7323.445175	9	5	4	13.182201
	Hackberry	4	14.5	165.1299639					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	11	95.03317777					
	Hackberry	4	18.5	268.8025214					
	Hackberry	4	17	226.9800692					
	Red Mulberry	7	24.5	471.4352476					
	Cottonwood	19	69.5	3793.669479					
	Green Ash	1	51.5	2083.072279					
55 E	Black Willow	22	14.5	165.1299639	3546.661756	13	6	5	13.831981
	Black Willow	22	20	314.1592654					
	Black Willow	22	22.5	397.6078202					
	snag	5	13	132.7322896					
	snag	5	17.5	240.5281875					
	snag	5	16.5	213.82465					
	snag	5	15	176.7145868					
	snag	5	10	78.53981634					
	snag	5	12.5	122.718463					
	Hackberry	4	18	254.4690049					
	Box Elder	14	17.5	240.5281875					
	Box Elder	14	28	615.7521601					

	Cottonwood	19	27.5	593.9573611					
56 W	Pecan	17	40.5	1288.249338	9189.94391	9	5	4	16.541899
	Pecan	17	41.5	1352.651987					
	Pecan	17	41.5	1352.651987					
	Hackberry	4	14.5	165.1299639					
	Hackberry	4	13	132.7322896					
	Hackberry	4	12	113.0973355					
	Hackberry	4	18	254.4690049					
	Cottonwood	19	75	4417.864669					
	Slippery Elm	12	12	113.0973355					
57 E	Cottonwood	19	19.5	298.6476516	1716.094987	7	4	2	0.961013
	Cottonwood	19	17.5	240.5281875					
	Cottonwood	19	16.5	213.82465					
	Cottonwood	19	12.5	122.718463					
	Black Willow	22	13	132.7322896					
	Black Willow	22	15	176.7145868					
	Black Willow	22	26	530.9291585					
58 W	Sycamore	23	34.5	934.820164	4168.697102	6	5	5	6.253046
	Sycamore	23	53	2206.183441					
	American Elm	18	17.5	240.5281875					
	Bois d'Arc	3	13.5	143.1388153					
	Red Mulberry	7	12	113.0973355					
	Green Ash	1	26	530.9291585					
59 E	Green Ash	1	30	706.8583471	2682.134728	10	5	3	4.023202
	Green Ash	1	10	78.53981634					
	Green Ash	1	18.5	268.8025214					
	Green Ash	1	24	452.3893421					
	Green Ash	1	16.5	213.82465					
	Green Ash	1	12	113.0973355					
	Green Ash	1	15	176.7145868					
	Green Ash	1	13	132.7322896					
	Cedar Elm	2	17.5	240.5281875					
	Honey Locust	10	19.5	298.6476516					
60 E	Hackberry	4	10.5	86.59014751	5095.270585	7	5	4	7.133379
	Hackberry	4	13	132.7322896					
	Hackberry	4	18	254.4690049					
	Hackberry	4	12	113.0973355					
	Cottonwood	19	72	4071.504079					
	Pecan	17	20	314.1592654					
	Red Mulberry	7	12.5	122.718463					
61 W	Cottonwood	19	33.5	881.4130889	2445.533531	6	5	3	2.200980
	Cottonwood	19	20	314.1592654					
	Red Mulberry	7	16	201.0619298					
	Red Mulberry	7	12.5	122.718463					
	Red Mulberry	7	25.5	510.7051557					
	Hackberry	4	23	415.4756284					
62 W	Box Elder	14	45	1590.431281	14253.99492	6	5	4	17.104794
	Box Elder	14	44.5	1555.284713					
	American Elm	18	16.5	213.82465					
	Cottonwood	19	112	9852.034562					
	Green Ash	1	25	490.8738521					
	Green Ash	1	26.5	551.5458602					

Random Plot Raw Tree Data

Plot	Species	Species Code	dbh (cm)	Basal area (cm^2)	Sum of Basal area	Total Trees	Canopy Layers	Species Richness	Complexity Index
R 1	Pecan	17	58	2642.079422	6167.731777	2	3	1	0.370063907
	Pecan	17	67	3525.652355					
R 2	Green Ash	1	12	113.0973355	2488.92678	2	5	2	0.497785356
	Bur Oak	9	55	2375.829444					
R 3	Green Ash	1	20	314.1592654	1962.71001	8	4	1	0.628067203
	Green Ash	1	20	314.1592654					
	Green Ash	1	20	314.1592654					
	Green Ash	1	11	95.03317777					
	Green Ash	1	10	78.53981634					
	Green Ash	1	21	346.3605901					
	Green Ash	1	14	153.93804					
	Green Ash	1	21	346.3605901					
R 4	Red Mulberry	7	13	132.7322896	2585.923453	6	4	4	2.482486515
	American Elm	18	46.5	1698.227179					
	American Elm	18	15	176.7145868					
	American Elm	18	18	254.4690049					
	Bur Oak	9	16	201.0619298					
	Hackberry	4	12.5	122.718463					
R 5	Bur Oak	9	97.5	7466.191291	7812.551881	2	4	2	1.250008301
	American Elm	18	21	346.3605901					
R 6	Cedar Elm	2	13	132.7322896	3004.540674	10	4	4	4.807265079
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	18.5	268.8025214					
	Shumard Oak	13	37	1075.210086					
	Shumard Oak	13	10.5	86.59014751					
	Shumard Oak	13	23.5	433.7361357					
	Mesquite	24	13.5	143.1388153					
	Bur Oak	9	11	95.03317777					
	Bur Oak	9	24.5	471.4352476					
	Bur Oak	9	13	132.7322896					
R 7	American Elm	18	41	1320.254313	6148.882221	8	5	3	7.378658665
	American Elm	18	30	706.8583471					
	American Elm	18	49	1885.74099					
	snag	5	15	176.7145868					
	snag	5	23	415.4756284					
	snag	5	24	452.3893421					
	Red Mulberry	7	26	530.9291585					
	Red Mulberry	7	29	660.5198554					
R 8	Hackberry	4	20	314.1592654	4620.890094	7	4	3	3.881547679
	Hackberry	4	25	490.8738521					
	Hackberry	4	40.5	1288.249338					
	Hackberry	4	28.5	637.9396582					
	Hackberry	4	43	1452.201204					
	snag	5	14	153.93804					
	American Elm	18	19	283.528737					
R 9	snag	5	17.5	240.5281875	4575.7297	5	5	3	3.431797275
	snag	5	35	962.1127502					
	snag	5	46.5	1698.227179					
	Red Mulberry	7	15.5	188.6919088					
	American Elm	18	43.5	1486.169675					
R 10	American Elm	18	45.5	1625.970548	4637.187106	10	5	4	9.274374212
	American Elm	18	34	907.9202769					
	American Elm	18	19.5	298.6476516					
	American Elm	18	15	176.7145868					
	American Elm	18	16	201.0619298					
	American Elm	18	11	95.03317777					
	American Elm	18	12.5	122.718463					
	Hackberry	4	35.5	989.7980354					
	Pecan	17	10.5	86.59014751					
	snag	5	13	132.7322896					
R 11	American Elm	18	27	572.5552611	9407.499201	8	5	3	11.28899904
	American Elm	18	37.5	1104.466167					
	American Elm	18	18	254.4690049					

	American Elm	18	70	3848.451001					
	American Elm	18	38.5	1164.156428					
	snag	5	30.5	730.6166415					
	Hackberry	4	20	314.1592654					
	Hackberry	4	42.5	1418.625433					
R 12	Hackberry	4	26.5	551.5458602	7207.206246	9	5	3	9.729728433
	Hackberry	4	32	804.2477193					
	Hackberry	4	19	283.528737					
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	42.5	1418.625433					
	Cedar Elm	2	52.5	2164.753688					
	snag	5	29.5	683.4927517					
	snag	5	26	530.9291585					
R13	Hackberry	4	61	2922.466566	7888.342804	5	5	3	5.916257103
	Hackberry	4	50	1963.495408					
	Hackberry	4	51.5	2083.072279					
	American Elm	18	15.5	188.6919088					
	Green Ash	1	30.5	730.6166415					
R 14	Shumard Oak	13	10	78.53981634	78.53981634	1	4	1	0.003141593
R 15	Cedar Elm	2	30	706.8583471	2249.57669	4	5	2	0.899830676
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	23	415.4756284					
	snag	5	35	962.1127502					
R16	Bur Oak	9	81	5152.99735	9986.730347	8	5	4	15.97876855
	Bur Oak	9	20	314.1592654					
	Bur Oak	9	63.5	3166.921744					
	Cedar Elm	2	14	153.93804					
	Cedar Elm	2	13	132.7322896					
	Cedar Elm	2	28	615.7521601					
	Green Ash	1	21	346.3605901					
	Hackberry	4	11.5	103.8689071					
R 17	Hackberry	4	26.5	551.5458602	3654.654004	8	4	2	2.338978562
	Hackberry	4	29.5	683.4927517					
	Hackberry	4	22.5	397.6078202					
	Hackberry	4	17.5	240.5281875					
	Hackberry	4	26	530.9291585					
	Hackberry	4	11.5	103.8689071					
	Hackberry	4	26	530.9291585					
	Green Ash	1	28	615.7521601					
R 18	Cedar Elm	2	12	113.0973355	1933.453929	15	5	2	2.900180893
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	12.5	122.718463					
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	13.5	143.1388153					
	Cedar Elm	2	12	113.0973355					
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	11.5	103.8689071					
	Cedar Elm	2	14.5	165.1299639					
	Cedar Elm	2	15	176.7145868					
	Cedar Elm	2	12.5	122.718463					
	Cedar Elm	2	16	201.0619298					
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	10	78.53981634					
	snag	5	13.5	143.1388153					
R 19	Cedar Elm	2	19	283.528737	2114.291856	10	4	1	0.845716742
	Cedar Elm	2	12	113.0973355					
	Cedar Elm	2	16.5	213.82465					
	Cedar Elm	2	16.5	213.82465					
	Cedar Elm	2	19	283.528737					
	Cedar Elm	2	22	380.1327111					
	Cedar Elm	2	12.5	122.718463					
	Cedar Elm	2	11	95.03317777					
	Cedar Elm	2	10	78.53981634					
	Cedar Elm	2	20.5	330.0635782					
R 20	Cottonwood	19	86	5808.804816	9828.472617	10	5	4	19.65694523
	snag	5	16.5	213.82465					
	Box Elder	14	29	660.5198554					
	Box Elder	14	16.5	213.82465					

	Box Elder	14	21.5	363.050301					
	Box Elder	14	23	415.4756284					
	American Elm	18	25	490.8738521					
	American Elm	18	24	452.3893421					
	American Elm	18	28	615.7521601					
	American Elm	18	27.5	593.9573611					
R 21	American Elm	18	33.5	881.4130889	3426.495837	3	4	2	0.822359001
	Hackberry	4	44.5	1555.284713					
	Hackberry	4	35.5	989.7980354					
R 22	snag	5	67	3525.652355	8493.492089	7	5	4	11.89088892
	Shumard Oak	13	18.5	268.8025214					
	Shumard Oak	13	61	2922.466566					
	Shumard Oak	13	19	283.528737					
	Shumard Oak	13	36	1017.87602					
	Hackberry	4	22	380.1327111					
	Cedar Elm	2	11	95.03317777					
R 23	Cedar Elm	2	10.5	86.59014751	5737.333584	10	5	4	11.47466717
	Cedar Elm	2	24	452.3893421					
	Red Mulberry	7	19.5	298.6476516					
	snag	5	12.5	122.718463					
	snag	5	32	804.2477193					
	American Elm	18	30	706.8583471					
	American Elm	18	16	201.0619298					
	American Elm	18	58	2642.079422					
	American Elm	18	14	153.93804					
	American Elm	18	18.5	268.8025214					
R 24	Hackberry	4	79	4901.669938	9646.063893	7	5	4	13.50448945
	Hackberry	4	25	490.8738521					
	Slippery Elm	12	62	3019.07054					
	Green Ash	1	29	660.5198554					
	American Elm	18	15.5	188.6919088					
	American Elm	18	10.5	86.59014751					
	American Elm	18	19.5	298.6476516					
R 25	Green Ash	1	10	78.53981634	8148.113246	15	4	3	14.66660384
	Green Ash	1	30	706.8583471					
	Green Ash	1	26	530.9291585					
	Green Ash	1	42	1385.44236					
	Green Ash	1	28.5	637.9396582					
	Green Ash	1	35	962.1127502					
	Green Ash	1	10.5	86.59014751					
	Green Ash	1	19	283.528737					
	Green Ash	1	30	706.8583471					
	Green Ash	1	18	254.4690049					
	Green Ash	1	19	283.528737					
	snag	5	11.5	103.8689071					
	snag	5	39.5	1225.417484					
	American Elm	18	12.5	122.718463					
	American Elm	18	31.5	779.3113276					
R 26	American Elm	18	24	452.3893421	5155.942593	11	4	3	6.805844223
	American Elm	18	41.5	1352.651987					
	American Elm	18	27	572.5552611					
	Hackberry	4	11	95.03317777					
	Hackberry	4	11.5	103.8689071					
	Hackberry	4	15	176.7145868					
	Hackberry	4	13	132.7322896					
	Hackberry	4	12	113.0973355					
	Hackberry	4	16.5	213.82465					
	Hackberry	4	25	490.8738521					
	snag	5	43	1452.201204					
R 27	Hackberry	4	20	314.1592654	7420.245498	10	4	3	8.904294598
	Hackberry	4	20.5	330.0635782					
	Hackberry	4	10	78.53981634					
	Hackberry	4	24	452.3893421					
	Hackberry	4	25	490.8738521					
	Hackberry	4	16	201.0619298					
	Hackberry	4	14	153.93804					
	snag	5	11.5	103.8689071					
	snag	5	10	78.53981634					
	American Elm	18	81.5	5216.810951					

R 28	American Elm	18	17.5	240.5281875	5936.432018	5	5	4	5.936432018
	snag	5	16.5	213.82465					
	snag	5	14	153.93804					
	Hackberry	4	40	1256.637061					
	Pecan	17	72	4071.504079					
R 29	Sycamore	23	33.5	881.4130889	6475.411508	8	5	4	10.36065841
	Sycamore	23	33	855.2985999					
	Sycamore	23	41	1320.254313					
	Box Elder	14	12.5	122.718463					
	Box Elder	14	17	226.9800692					
	Box Elder	14	30.5	730.6166415					
	Red Mulberry	7	36	1017.87602					
	Hackberry	4	41	1320.254313					
R 30	Bur Oak	9	78	4778.362426	7169.114435	8	5	4	11.4705831
	Box Elder	14	21	346.3605901					
	Box Elder	14	18	254.4690049					
	Bois d'arc	3	16	201.0619298					
	Hackberry	4	41	1320.254313					
	snag	5	11	95.03317777					
	snag	5	11	95.03317777					
	snag	5	10	78.53981634					
R 31	American Elm	18	13.5	143.1388153	8648.804575	7	5	5	15.13540801
	American Elm	18	81.5	5216.810951					
	Slippery Elm	12	21	346.3605901					
	Green Ash	1	31	754.767635					
	Green Ash	1	47.5	1772.054606					
	Red Mulberry	7	15.5	188.6919088					
	snag	5	17	226.9800692					
R 32	Cedar Elm	2	41.5	1352.651987	6107.059769	5	5	3	4.580294827
	Cedar Elm	2	34	907.9202769					
	Cedar Elm	2	54.5	2332.828895					
	Hackberry	4	35	962.1127502					
	snag	5	26.5	551.5458602					
R 33	Cedar Elm	2	26	530.9291585	2733.578308	7	5	2	1.913504815
	Cedar Elm	2	22.5	397.6078202					
	Cedar Elm	2	31	754.767635					
	Cedar Elm	2	15.5	188.6919088					
	Cedar Elm	2	24	452.3893421					
	Cedar Elm	2	20	314.1592654					
	snag	5	11	95.03317777					
R 34	Cedar Elm	2	10.5	86.59014751	362.4612524	3	5	2	0.108738376
	Cedar Elm	2	13.5	143.1388153					
	snag	5	13	132.7322896					
R 35	Hackberry	4	16	201.0619298	2836.661817	8	4	3	2.723195344
	Hackberry	4	21	346.3605901					
	Hackberry	4	10.5	86.59014751					
	Hackberry	4	35.5	989.7980354					
	Hackberry	4	17.5	240.5281875					
	Hackberry	4	18	254.4690049					
	snag	5	17	226.9800692					
	Honey Locust	10	25	490.8738521					
R 36	Box Elder	14	15.5	188.6919088	1153.357203	4	5	2	0.461342881
	Box Elder	14	14.5	165.1299639					
	Box Elder	14	17	226.9800692					
	Green Ash	1	27	572.5552611					
R 37	Green Ash	1	56	2463.00864	4619.711997	3	5	2	1.385913599
	Green Ash	1	35	962.1127502					
	snag	5	39	1194.590607					
R 38	Box Elder	14	25.5	510.7051557	11494.49847	5	5	3	8.620873853
	Box Elder	14	22	380.1327111					
	Green Ash	1	78	4778.362426					
	Green Ash	1	84	5541.769441					
	snag	5	19	283.528737					
R 39	vine	26	11	95.03317777	7248.046951	6	5	4	8.697656341
	Bur Oak	9	69.5	3793.669479					
	Slippery Elm	12	19	283.528737					
	Slippery Elm	12	13	132.7322896					
	American Elm	18	57.5	2596.722678					
	American Elm	18	21	346.3605901					

R 40	Red Mulberry	7	20.5	330.0635782	3319.288988	4	5	3	1.991573393
	Hackberry	4	46	1661.902514					
	Hackberry	4	39	1194.590607					
	American Elm	18	13	132.7322896					
R 41	Cedar Elm	2	22	380.1327111	4543.724725	9	5	2	4.089352252
	Cedar Elm	2	31	754.767635					
	Cedar Elm	2	28	615.7521601					
	Cedar Elm	2	17	226.9800692					
	Cedar Elm	2	15.5	188.6919088					
	Cedar Elm	2	33	855.2985999					
	Cedar Elm	2	29	660.5198554					
	Cedar Elm	2	29	660.5198554					
	snag	5	16	201.0619298					
R 42	Hackberry	4	29.5	683.4927517	3088.185578	9	3	4	3.335240425
	Hackberry	4	24	452.3893421					
	Hackberry	4	21.5	363.050301					
	Hackberry	4	23	415.4756284					
	Hackberry	4	22	380.1327111					
	Cedar Elm	2	14.5	165.1299639					
	snag	5	24.5	471.4352476					
	snag	5	10	78.53981634					
	Bois d'arc	3	10	78.53981634					
R 43	Green Ash	1	13.5	143.1388153	1792.867657	5	5	2	0.896433829
	Green Ash	1	25	490.8738521					
	Green Ash	1	15.5	188.6919088					
	Green Ash	1	22.5	397.6078202					
	Hackberry	4	27	572.5552611					
R 44	Hackberry	4	52	2123.716634	8708.102137	5	5	4	8.708102137
	Hackberry	4	37	1075.210086					
	Red Mulberry	7	18	254.4690049					
	Bur Oak	9	80.5	5089.576448					
	Green Ash	1	14.5	165.1299639					
R 45	Cedar Elm	2	19.5	298.6476516	3338.138544	9	5	2	3.00432469
	Cedar Elm	2	22	380.1327111					
	Cedar Elm	2	17.5	240.5281875					
	Cedar Elm	2	33	855.2985999					
	Cedar Elm	2	10	78.53981634					
	Cedar Elm	2	24.5	471.4352476					
	snag	5	25.5	510.7051557					
	snag	5	15.5	188.6919088					
	snag	5	20	314.1592654					
R 46	Box Elder	14	30.5	730.6166415	3423.157895	5	4	2	1.369263158
	Box Elder	14	39	1194.590607					
	Box Elder	14	33.5	881.4130889					
	Box Elder	14	16	201.0619298					
	snag	5	23	415.4756284					
R 47	Hackberry	4	38	1134.114948	8715.759769	5	5	2	4.357879884
	Hackberry	4	55	2375.829444					
	Hackberry	4	56	2463.00864					
	Hackberry	4	40	1256.637061					
	Cedar Elm	2	43.5	1486.169675					
R 48	American Elm	18	37	1075.210086	7723.21284	8	4	5	12.35714054
	Hackberry	4	68	3631.681108					
	Hackberry	4	29.5	683.4927517					
	snag	5	10	78.53981634					
	snag	5	12	113.0973355					
	Cedar Elm	2	20	314.1592654					
	Cedar Elm	2	16	201.0619298					
	Bur Oak	9	45.5	1625.970548					
R 49	Slippery Elm	12	13.5	143.1388153	1025.730001	6	5	3	0.923157001
	Green Ash	1	12.5	122.718463					
	Green Ash	1	19.5	298.6476516					
	Green Ash	1	11	95.03317777					
	Green Ash	1	16	201.0619298					
	American Elm	18	14.5	165.1299639					
R 50	Green Ash	1	27	572.5552611	1595.340019	5	2	4	0.638136008
	Bois d'arc	3	16	201.0619298					
	Black Willow	22	19.5	298.6476516					
	Black Willow	22	21	346.3605901					

	Cedar Elm	2	15	176.7145868					
R 51	Cottonwood	19	36.5	1046.346703	1132.936851	2	4	2	0.181269896
	Hackberry	4	10.5	86.59014751					
R 52	snag	5	38	1134.114948	7985.339477	3	5	3	3.593402765
	American Elm	18	46.5	1698.227179					
	Green Ash	1	81	5152.99735					
R 53	Hackberry	4	14.5	165.1299639	5642.104056	4	4	2	1.805473298
	Hackberry	4	11.5	103.8689071					
	Green Ash	1	63.5	3166.921744					
	Green Ash	1	53	2206.183441					
R 54	Green Ash	1	46	1661.902514	3493.254681	6	3	4	2.515143371
	Green Ash	1	37	1075.210086					
	Bois d'arc	3	12.5	122.718463					
	Bois d'arc	3	12	113.0973355					
	American Elm	18	23.5	433.7361357					
	snag	5	10.5	86.59014751					
R 55	Black Willow	22	22.5	397.6078202	2272.549586	3	4	2	0.545411901
	Black Willow	22	15	176.7145868					
	Green Ash	1	46.5	1698.227179					
R 56	Box Elder	14	18	254.4690049	2048.51476	9	3	3	1.659296955
	Box Elder	14	16.5	213.82465					
	Box Elder	14	11	95.03317777					
	Box Elder	14	11.5	103.8689071					
	Box Elder	14	17.5	240.5281875					
	Box Elder	14	19.5	298.6476516					
	Box Elder	14	16	201.0619298					
	Cottonwood	19	24	452.3893421					
	snag	5	15.5	188.6919088					
R 57	Green Ash	1	57.5	2596.722678	4307.712577	3	5	3	1.93847066
	Hackberry	4	32.5	829.5768101					
	Chittamwood	6	33.5	881.4130889					
R 58	Bois d'arc	3	13	132.7322896	3027.906269	10	4	5	6.055812539
	Bois d'arc	3	14.5	165.1299639					
	Green Ash	1	13	132.7322896					
	Green Ash	1	25	490.8738521					
	Hackberry	4	25.5	510.7051557					
	Hackberry	4	18	254.4690049					
	Hackberry	4	17	226.9800692					
	snag	5	23.5	433.7361357					
	snag	5	10.5	86.59014751					
	Chinaberry	25	27.5	593.9573611					
R 59	Green Ash	1	17	226.9800692	941.6923979	5	3	3	0.423761579
	Green Ash	1	20	314.1592654					
	Black Willow	22	11	95.03317777					
	Box Elder	14	17	226.9800692					
	Box Elder	14	10	78.53981634					
R 60	Cedar Elm	2	38	1134.114948	3442.40015	4	4	1	0.550784024
	Cedar Elm	2	37	1075.210086					
	Cedar Elm	2	29	660.5198554					
	Cedar Elm	2	27	572.5552611					
R 61	snag	5	17.5	240.5281875	1528.581176	5	4	4	1.22286494
	snag	5	12	113.0973355					
	American Elm	18	36	1017.87602					
	Box Elder	14	10	78.53981634					
	Hackberry	4	10	78.53981634					
R 62	Hackberry	4	25.5	510.7051557	1437.867688	6	4	4	1.38035298
	Hackberry	4	13.5	143.1388153					
	Hackberry	4	19	283.528737					
	American Elm	18	14	153.93804					
	Green Ash	1	13	132.7322896					
	snag	5	16.5	213.82465					
R 63	Hackberry	4	27	572.5552611	2388.788514	4	5	2	0.955515406
	Hackberry	4	30	706.8583471					
	Hackberry	4	28.5	637.9396582					
	snag	5	24.5	471.4352476					

Summary of Avian Plot Tree Data - Importance Values

Species	Dbh (cm)	Basal area (cm^2)	Basal area (m^2)	Dominance (m^2/ha)	Rel. Dom.	Total Trees	Density (trees/ha)	Rel. Dens.	Freq.	Rel. Freq.	Imp. Val.
Green ash	2433	4647245.111	464.725	363.066	28.024	65	50.781	16.667	29	14.573	19.754
Cedar elm	1294	1315098.959	131.510	102.742	7.930	39	30.469	10.000	17	8.543	8.824
Bois d’arc	193.5	29407.074	2.941	2.297	0.177	8	6.250	2.051	5	2.513	1.580
Hackberry	3263	8362266.978	836.227	653.302	50.426	120	93.750	30.769	47	23.618	34.938
Snag	1222	1172822.511	117.282	91.627	7.072	47	36.719	12.051	29	14.573	11.232
Chittamwood	35.5	989.798	0.099	0.077	0.006	1	0.781	0.256	1	0.503	0.255
Red Mulberry	170	22698.007	2.270	1.773	0.137	10	7.813	2.564	8	4.020	2.240
Black walnut	13.5	143.139	0.014	0.011	0.001	1	0.781	0.256	1	0.503	0.253
Bur oak	345.5	93753.175	9.375	7.324	0.565	7	5.469	1.795	7	3.518	1.959
Honey locust	67.5	3578.470	0.358	0.280	0.022	4	3.125	1.026	3	1.508	0.852
Hawthorn	12	113.097	0.011	0.009	0.001	1	0.781	0.256	1	0.503	0.253
Slippery elm	253.5	50471.453	5.047	3.943	0.304	9	7.031	2.308	5	2.513	1.708
Shumard oak	59.5	2780.506	0.278	0.217	0.017	1	0.781	0.256	1	0.503	0.259
Box Elder	367.5	106072.931	10.607	8.287	0.640	14	10.938	3.590	9	4.523	2.917
Pecan	524	215651.486	21.565	16.848	1.300	17	13.281	4.359	7	3.518	3.059
American elm	620.5	302394.197	30.239	23.625	1.823	23	17.969	5.897	16	8.040	5.254
Cottonwood	554.5	241486.570	24.149	18.866	1.456	12	9.375	3.077	8	4.020	2.851
Post oak	25	490.874	0.049	0.038	0.003	2	1.563	0.513	1	0.503	0.339
Blackjack oak	11	95.033	0.010	0.007	0.001	1	0.781	0.256	1	0.503	0.253
Black willow	111	9676.891	0.968	0.756	0.058	6	4.688	1.538	2	1.005	0.867
Sycamore	87.5	6013.205	0.601	0.470	0.036	2	1.563	0.513	1	0.503	0.351
Sum	**11663**	**16583249.5**	**1658.3249**	**1295.56636**	**100**	**390**	**304.6875**	**100**	**199**	**100**	**100**

Summary of Random Plot Tree Data - Importance Values

Species	Dbh (cm)	Basal area (cm^2)	Basal area (m^2)	Dominance (m^2/ha)	Rel. Dom.	Total Trees	Density (trees/ha)	Rel. Dens.	Freq.	Rel. Freq.	Imp. Val.
Green ash	1534	1846959.796	184.696	293.168	16.048	53	84.127	6.600	22	11.828	11.492
Cedar elm	1467	1689094.765	168.909	268.110	14.677	71	112.698	8.842	18	9.677	11.065
Bois d’arc	94	6939.778	0.694	1.102	0.060	7	11.111	0.872	5	2.688	1.207
Hackberry	2367	4398482.810	439.848	698.172	38.219	85	134.921	10.585	32	17.204	22.003
Snag	1096	943432.840	94.343	149.751	8.198	52	82.540	6.476	35	18.817	11.164
Chittamwood	33.5	881.413	0.088	0.140	0.008	1	1.587	0.125	1	0.538	0.223
Red Mulberry	193	29255.296	2.926	4.644	0.254	9	14.286	1.121	9	4.839	2.071
Bur oak	655	336955.447	33.696	53.485	2.928	13	20.635	1.619	9	4.839	3.128
Honey locust	25	490.874	0.049	0.078	0.004	1	1.587	0.125	1	0.538	0.222
Slippery elm	128.5	12968.691	1.297	2.059	0.113	404	641.270	50.311	4	2.151	17.525
Shumard oak	215.5	36474.087	3.647	5.790	0.317	8	12.698	0.996	3	1.613	0.975
Box Elder	549.5	237151.172	23.715	37.643	2.061	28	44.444	3.487	9	4.839	3.462
Pecan	207.5	33816.300	3.382	5.368	0.294	4	6.349	0.498	3	1.613	0.802
American elm	1557	1902778.044	190.278	302.028	16.533	53	84.127	6.600	25	13.441	12.192
Cottonwood	146.5	16856.412	1.686	2.676	0.146	3	4.762	0.374	3	1.613	0.711
Black willow	89	6221.139	0.622	0.987	0.054	5	7.937	0.623	3	1.613	0.763
Sycamore	107.5	9076.258	0.908	1.441	0.079	3	4.762	0.374	1	0.538	0.330
Mesquite	13.5	143.139	0.014	0.023	0.001	1	1.587	0.125	1	0.538	0.221
Chinaberry	27.5	593.957	0.059	0.094	0.005	1	1.587	0.125	1	0.538	0.222
vine	11	95.033	0.010	0.015	0.001	1	1.587	0.125	1	0.538	0.221
Sum	**10516**	**11508667.3**	**1150.8667**	**1826.77258**	**100**	**803**	**1274.603**	**100**	**186**	**100**	**100**

Avian Plot Forest Survey Data

Station	Stand Type	Seral Stage	Edge	Edge Type	# Can. Layers	Ground	Shrub	Understory	Midstory	Canopy Ht	Emergents	FHD	Canopy Cover	Corr/Patch
1 E	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.9	1.9	2.6	10.3	27.7		0.4222	0.9	C
2 E	mixed/even	stem exclusion	Y	abrupt/dense	4	0.8	1.4		6	16.6		0.3944	0.95	C
3 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.8	1.5	4	11.1	22.2		0.5150	0.8	C
4 W	mixed/uneven	stem exclusion	Y	transtnl/dense	4	1		1.5	4	19.7		0.2985	0.8	C
5 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.9	1.5	2.9	9.6	23.3		0.4601	0.65	C
6 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.8	1.4		5	18.6		0.3443	0.75	C
7 W	mixed/uneven	old growth	N		5	1	1.4	3.9	6.9	22.6		0.4230	0.75	C
8 E	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.9		3	9.2	24.8		0.4202	0.65	C
9 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.6	1.8	4.9	15.3	24.7		0.5340	0.75	P
10 W	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.7	1.2	2.9	7.7	22.2		0.4345	0.65	C
11E	mixed/uneven	undrstry reinit	N		4	0.9		2.9	6.7	24.4		0.3688	0.8	P
12 E	mixed/uneven	stem exclusion	Y	transtnl/dense	4	0.9		2.7	6.3	17.1		0.4387	0.85	P
13 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.8	1.5	4.4	8.3	20.8		0.4925	0.75	P
14 W	mixed/even	stand initiation	Y	abrupt/dense	3	0.8	1.2			5.6		0.2849	0.95	P
15 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.7	1.6	3.2	6	19.3		0.4370	0.85	P
16 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.3	3.8	8.7	19.4		0.5048	0.35	C
17 E	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.6	1.1	2.3	4.4	12		0.4807	0.85	C
18 E	mixed/uneven	stem exclusion	Y	transtnl/dense	4	0.6	1.1	3.2		9		0.4186	0.55	C
19 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1.1		3.6	6	13.7		0.4959	0.6	C
20 E	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.6		6.3	11.3	21.7		0.4956	0.55	C
21 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.8	1	2.3	10.8	13.8		0.4687	0.6	C
22 E	mixed/uneven	old growth	Y	abrupt/dense	5	0.9	1.8	4.8	7.8	22.2		0.4697	0.8	C
23 W	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.9	4.4	12.7	13.3		0.4886	0.85	C
24 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1.2	1.6		5.1	23.8		0.3000	0.8	C
25 E	mixed/uneven	old growth	Y	abrupt/dense	5	0.7	1.7	4	7.7	27.7		0.4011	0.6	C
26 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.4	3.4	9.6	15		0.5576	0.65	C
27 W	mixed/uneven	undrstry reinit	Y	abrupt/open	4	1.1		2.3	5.3	29.3		0.2827	0.85	C
28 E	mixed/uneven	undrstry reinit	Y	abrupt/open	3	0.8		4.7		20.2		0.2817	0.55	C
29 W	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.4	4.2	10.2	26.5		0.4614	0.75	C
30 W	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.7		5.7	10.8	17.1		0.5294	0.75	C
31 E	mixed/even	stem exclusion	N		3	0.8			6.7	20.2		0.3286	0.8	C
32 E	mixed/uneven	stem exclusion	N		4	0.8	0.8		8.9	12.8	20.8	0.5098	0.85	P
33 E	mixed/even	stand initiation	Y	abrupt/dense	4	0.3	0.5		7.5	9.7		0.3298	0.7	C
34 W	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.9	1.8	3	6.9	25.5		0.3896	0.75	C
35 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1	1.6		6.5	15.1		0.4316	0.75	C
36 E	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	1		2.9	7.1	19		0.4395	0.7	C
37 W	mixed/uneven	old growth	Y	abrupt/dense	5	0.9	1.4	3.7	4.9	28		0.2959	0.9	C
38 W	mixed/uneven	undrstry reinit	N		4	0.9		3.6	9.6	16.5		0.5156	0.85	P
39 W	mixed/uneven	undrstry reinit	N		4	0.8		2.1	5.8	17		0.4114	0.7	P
40 W	mixed/uneven	undrstry reinit	N		4	0.7		2.5	6.6	14.5		0.4748	0.7	P
41 W	mixed/uneven	undrstry reinit	N		4	1		1.9	7.3	18.2		0.4237	0.5	P
42 W	mixed/uneven	undrstry reinit	N		3	0.7			5.8	22.1		0.2920	0.7	P
43 W	mixed/uneven	undrstry reinit	N		4	0.8		1.7	7.1	18.8		0.4053	0.75	P
44 E	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.8	1.2	3.5	5.2	20.8		0.3758	0.75	C
45 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.9	1	2.7		22.5		0.2000	0.75	C

46 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.8	1.4	2.5	4	21.5		0.3161	0.6	C
47 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	1.2	1.5	3.1	6.6	18.3		0.4610	0.75	C
48 E	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.9	1.2	2.5		9.3	22.2	0.4483	0.7	C
49 E	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.9	1.4	2.5	4.3	15		0.4209	0.8	C
50 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	1	1.4	3	9.3	30.4		0.3926	0.9	C
51 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.7	1.3	4.2	8	30.2		0.3809	0.85	C
52 E	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.9	1.4	3.9	7.3	19.7		0.4737	0.75	P
53 E	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.9	1.3	2.9	6.4	15.7		0.4929	0.8	C
54 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	1.1	1.4	2.6	11	41.2		0.3420	0.75	C
55 E	mixed/even	stem exclusion	N		6	0.7	1.2	2.7	6.5	15.6	21.3	0.6127	0.75	P
56 W	mixed/uneven	undrstry reinit	N		5	0.3	1.1	2.6	11.2	18.9		0.4885	0.75	P
57 E	pure/even	stand initiation	Y	transtnl/dense	4	1.1	1.8	5.8		16.9		0.4025	0.3	C
58 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.7	1.5	5.3	9.5	34.8		0.3883	0.85	C
59 E	mixed/uneven	stem exclusion	N		5	1	1.3	4.7	6.9	18.1		0.4756	0.8	C
60 E	mixed/uneven	undrstry reinit	N		5	0.6	1.1	4.8	9.1	39.1		0.3427	0.85	P
61 W	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.6	1.3	4.7	7.4	30.1		0.3652	0.75	P
62 W	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	1	1.6	5.8	13	39		0.4258	0.75	P

Random Plot Forest Survey Data

Station	Stand Type	Seral Stage	Edge	Edge Type	# Can. Layers	Ground	Shrub	Understory	Midstory	Canopy Ht	Emergents	FHD	Canopy Cover
R 1	mixed/even	stand initiation	Y	abrupt/dense	3		1.5			5.4	25.8	0.2718	85%
R 2	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.6	1.2	3.6	8.1	23.7		0.4441	95%
R 3	pure/even	stem exclusion	Y	transtnl/dense	4	0.9	2	5.5		22.3		0.3568	80%
R 4	mixed/uneven	stem exclusion	Y	abrupt/open	4	0.6	1.4		7.9	20.1		0.3652	85%
R 5	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	0.5	1.7	4.6		28.6		0.2795	75%
R 6	mixed/uneven	stem exclusion	Y	abrupt/dense	4	0.4	1.3		5.4	15.9		0.3597	90%
R 7	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.2	2.2	8.1	21.2		0.4315	80%
R 8	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.6	1.3	5.1		23.1		0.3117	95%
R 9	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.3	1.4	3.7	10.4	29		0.4205	90%
R 10	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.3	3.1	7.1	24.5		0.4226	80%
R 11	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.7	3.6	7.3	22.2		0.4590	70%
R 12	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.5	1.7	3.9	7.3	23.3		0.4555	80%
R 13	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.5	1.2	4.2	7.5	20.6		0.4670	85%
R 14	mixed/uneven	stand initiation	Y	abrupt/dense	4	0.4	1.3			8.7	10.1	0.3485	80%
R 15	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.4	1.5	3.9	7.8	13.5		0.5242	80%
R 16	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.4	1.8	3.7	8	17		0.5014	65%
R 17	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.5	1.4	3.7		19.3		0.3132	70%
R 18	pure/uneven	stem exclusion	Y	abrupt/open	5	0.2	0.9		4.7	17	23.7	0.3849	90%
R 19	pure/uneven	stem exclusion	Y	abrupt/open	4	0.3	1.4		4.7	16.5		0.3426	95%
R 20	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.3	1.2	3.8	9.5	14.8		0.5000	90%
R 21	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	0.5	1.3		5.9	24.4		0.3103	85%
R 22	mixed/uneven	stem exclusion	Y	abrupt/open	5	0.9	1.5	4.8	7.5	17.4		0.5208	75%
R 23	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.7	2	4.4	9.8	23.9		0.4836	70%
R 24	mixed/uneven	stem exclusion	Y	abrupt/open	5	1	1.8	4.4	7.4	22.2		0.4894	65%
R 25	mixed/uneven	undrstry reinit	Y	abrupt/open	4	1	1.7		6.7	17		0.4048	70%
R 26	mixed/uneven	stem exclusion	Y	abrupt/open	4	0.6	1.2		5.1	23.3		0.3068	75%

R 27	mixed/uneven	stem exclusion	Y	abrupt/open	4	0.6	1.4		5.8	26.3		0.3057	75%
R 28	mixed/uneven	undrstry reinit	Y	transtnl/open	5	0.5	1.4	3.8	7.7	25.3		0.4357	80%
R 29	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.3	1.6	5.1	9.2	17.6		0.5062	80%
R 30	mixed/uneven	undrstry reinit	Y	abrupt/dense	5	0.9	1.4	4.4	11.5	27		0.4640	75%
R 31	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.6	1.4	3.9	10.1	20.4		0.4832	90%
R 32	mixed/uneven	stem exclusion	Y	abrupt/dense	5	0.6	1.3	3.6	5.3	15		0.5009	70%
R 33	pure/uneven	stem exclusion	N		5	0.4	1.4	3.5	7.3	13.1		0.5193	75%
R 34	pure/even	stand initiation	Y	abrupt/dense	5	0.2	1		4	8.4	13.4	0.4306	80%
R 35	mixed/uneven	undrstry reinit	Y	abrupt/dense	4	0.2	1.4		5.2	18.2		0.3291	90%
R 36	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.2	1.8	3.9	9.2	25.7		0.4409	85%
R 37	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.1	1.4	4.7	7.6	20.7		0.4596	75%
R 38	mixed/uneven	old growth	Y	abrupt/dense	5	0.2	1.6	3.1	8.1	26.1		0.4146	85%
R 39	mixed/uneven	old growth	Y	abrupt/dense	5	0.1	1.3	3	7.5	23.7		0.4103	85%
R 40	mixed/uneven	old growth	Y	abrupt/dense	5	0.1	1.5	2.8	10.8	22.2		0.4374	70%
R 41	mixed/uneven	undrstry reinit	N		5	0.1	1.2	2.5	5.5	18.8		0.4161	75%
R 42	mixed/uneven	undrstry reinit	N		3	0.1			5.4	16.8		0.2523	60%
R 43	mixed/uneven	undrstry reinit	N		5	0.1	1.7	3.4	5.2	15.3		0.4781	70%
R 44	mixed/uneven	undrstry reinit	Y	transtnl/open	5	0.3	1.6	3.5	10.8	28		0.4292	80%
R 45	mixed/uneven	stem exclusion	Y	abrupt/open	5	0.2	1.3	4.6	8.9	17		0.4919	75%
R 46	mixed/uneven	undrstry reinit	Y	abrupt/open	4	0.8	1.4		7.1	16		0.3977	80%
R 47	mixed/uneven	undrstry reinit	Y	abrupt/open	5	0.2	1.2	7.5	13	33.5		0.4423	80%
R 48	mixed/uneven	old growth	Y	abrupt/dense	4	0.5	1.9		7.5	22.9		0.3548	80%
R 49	mixed/uneven	stand initiation	Y	transtnl/dense	5	0.2	1.6	4.3	13.4	18.8		0.4874	60%
R 50	mixed/even	stand initiation	Y	transtnl/open	2	0.1				10.8		0.0227	75%
R 51	mixed/uneven	stand initiation	Y	transtnl/dense	4	0.1	1.2		6.9	14.8		0.3573	60%
R 52	mixed/uneven	stem exclusion	N		5	0.1	1.2	2.4	7.3	18.8		0.4284	90%
R 53	mixed/uneven	undrstry reinit	N		4	0.2		2.5	5	28		0.2958	70%
R 54	mixed/uneven	undrstry reinit	Y	abrupt/dense	3	0.1			6.4	30.9		0.2066	75%
R 55	mixed/even	stem exclusion	Y	transtnl/dense	4	0.1	1.7		5.9	16.5		0.3537	65%
R 56	pure/even	stem exclusion	N		3	0.2			5.6	14.6		0.2778	50%
R 57	mixed/uneven	stem exclusion	Y	transtnl/dense	5	0.2	1.5	4	6.1	13.9		0.5068	80%
R 58	mixed/uneven	stem exclusion	Y	abrupt/dense	4	0.5	1.3		4.9	17		0.3495	75%
R 59	mixed/uneven	stand initiation	Y	abrupt/dense	3	0.3			4	11.7		0.2823	80%
R 60	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.6		3	4.8	19.5		0.3802	85%
R 61	mixed/even	stand initiation	Y	transtnl/dense	4	0.2	1.3		5.8	15.8		0.3517	60%
R 62	mixed/uneven	undrstry reinit	Y	transtnl/dense	4	0.3		3.6	6.9	25.3		0.3627	50%
R 63	mixed/uneven	undrstry reinit	Y	transtnl/dense	5	0.3	1.3	2.8	5.1	25.8		0.3786	65%

APPENDIX C

ZELIG INPUT FILES

ZELIG Control Driver File

```
ZELIG version 2.3.
   1     * MODE
   0     * INDATA
  10     * NROWS
  10     * NCOLS
 500     * NYRS
  50     * IPRT
  50     * IPCH
  10     * ITRX
  50     * ILAI
  50     * ILOG
```

ZELIG Species Driver File

```
5  Species parameters for Greenbelt  (under testing)
FRpe  Fraxinus pennsylvanica  Green ash
  220 130 37.000 -0.0188 0.6110 1100  9  1950 5500  350 3  5 5  25
ULcr  Ulmus crassifolia       Cedar elm
  200 102 32.000 -0.0266 1.1100 1100  9  4200 6500  460 3  5 5  20
CEsp  Celtis spp.             Hackberry
  260  95 35.000 -0.0216 0.8210 1100  9  3400 5500  450 1  1 3  25
QUma  Quercus macrocarpa      Bur oak
  400 163 50.000 -0.0127 1.1000 1100  8  1950 5500  430 1  1 1  30
CAil  Carya illinoensis       Pecan
  300 160 45.000 -0.0132 1.0900 1100  9  3400 5500  227 3  3 3  20
```

ZELIG Site Driver File

```
Greenbelt bottomland forest
33.0  97.00 180.0
 0.65  0.42 0.58
0.400
150  25
    2
   10 20.00   Ovan clay
 10.00  4.5  2.5
 10.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
 14.00  4.5  2.5
   10 20.00   Clay Loam
 10.00  3.83 2.10
 10.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 18.00  3.83 2.10
 7.0  8.9 13.5 18.1 22.3 26.6 28.8 28.9 25.1 19.2 12.8  8.2
 2.4  2.4  2.3  1.4  1.2  1.2  1.1  1.2  1.4  1.5  1.8  1.9
 7.2  8.4  9.6  14.0  18.0  12.8  8.7  7.7  12.0  12.6  9.5  8.7
 4.0  3.9  4.1  6.6  6.5  6.3  4.0  4.3  5.9  7.0  5.5  4.5
249.5 318.4 404.4 481.8 533.5 593.7 602.3 550.7 447.4 361.4 266.7 232.3
  23.4  35.8
1111111111
1111111111
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```

APPENDIX D

ZELIG OUTPUT FILES

These files show ZELIG output for a 200-year simulation. Print intervals are indicated with each file. Only the print, log, and tracer files are shown; the punch and LAI files were omitted, because they were not important for this project.

ZELIG Output File Z.pri (printed at 100-yr intervals**)**

```
ZELIG version 2.3.

    ZELIG is in interactive-grid mode
    Max zone-of-influence:   600.0 sq. m (4 plots)
    Vertical step size through leaf profile:   9 m

Location:  Greenbelt bottomland for

    Lat:  33.0     Long:  97.0
    Elevation:  180.0 m

Number of soil types:    3

  Soil type:    1      Ovan clay

    Fertility:  20.0 Mg/ha/yr

    Depth, FC, and WP per layer:
      1   10.00    4.50  2.50
      2   10.00    4.50  2.50
      3   14.00    4.50  2.50
      4   14.00    4.50  2.50
      5   14.00    4.50  2.50
      6   14.00    4.50  2.50
      7   14.00    4.50  2.50
      8   14.00    4.50  2.50
      9   14.00    4.50  2.50
     10   14.00    4.50  2.50

  Soil type:    2      Sandy Loam

    Fertility:  20.0 Mg/ha/yr

    Depth, FC, and WP per layer:
      1   10.00    2.80   .90
      2   10.00    2.80   .90
      3   10.00    2.80   .90
      4   10.00    2.80   .90
      5   10.00    2.80   .90
      6   10.00    2.80   .90
      7   10.00    2.80   .90
      8   10.00    2.80   .90
      9   10.00    2.80   .90
     10   10.00    2.80   .90

  Soil type:    3      Clay Loam

    Fertility:  20.0 Mg/ha/yr

    Depth, FC, and WP per layer:
      1   10.00    3.83  2.10
      2   10.00    3.83  2.10
      3   18.00    3.83  2.10
      4   18.00    3.83  2.10
      5   18.00    3.83  2.10
      6   18.00    3.83  2.10
      7   18.00    3.83  2.10
      8   18.00    3.83  2.10
      9   18.00    3.83  2.10
     10   18.00    3.83  2.10

Number of plots:  100 (10 rows, 10 columns)
    Output samples are  1.50-ha aggregates

Soils map for grid:

    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111
    1111111111

Number of species in driver file:    5

  Species names and mnemonics:

 1  FRpe  Fraxinus pennsylvanica    Green ash
 2  ULcr  Ulmus crassifolia         Cedar elm
 3  CEsp  Celtis spp.               Hackberry
 4  QUma  Quercus macrocarpa        Bur oak
 5  CAil  Carya illinoensis         Pecan

Number of species available for simulation:    5

Tree life-history parameters ...
  Species max Age, Dbh, Ht; G, Form; GDDs; L, M, N; Seeds, Sprouts:

 1  FRpe  220.0 130.0  37.0  1100.0  9  1950.0 5500.0  350 3   5.0 5
 2  ULcr  200.0 102.0  32.0  1100.0  9  4200.0 6500.0  460 3   5.0 5
```

```
 3  CEsp  260.0  95.0  35.0  1100.0  9  3400.0 5500.0  450 1   1.0 3
 4  QUma  400.0 163.0  50.0  1100.0  8  1950.0 5500.0  430 1   1.0 1
 5  CAil  300.0 160.0  45.0  1100.0  9  3400.0 5500.0  227 3   3.0 3

Simulation initiated from bare ground


Simulation year:  100

Stand Structure by Species:

  Species Dbh Distribution (#/ha, in 10-cm classes),

    FRpe  236.0 165.3  59.3    .7    .0   .0   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    ULcr   35.3   8.0  40.0  52.7   2.0   .0   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    CEsp   58.0  26.0  24.0  31.3  45.3  8.7   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    QUma   25.3    .0   4.0   8.0  14.0  8.0   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    CAil    4.7    .0   6.7  12.7  14.0   .0   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

    All:  359.3 199.3 134.0 105.3  75.3 16.7   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

Species Composition:

  Species Density, Rel. D;   BA, Rel. BA;  IV200; Frequency:

    FRpe      461.3  51.8     6.1  16.9    34.39      .98
    ULcr      138.0  15.5     7.4  20.6    18.05      .85
    CEsp      193.3  21.7    13.9  38.6    30.14      .92
    QUma       59.3   6.7     4.9  13.7    10.16      .57
    CAil       38.0   4.3     3.7  10.2     7.26      .42

Stand Aggregates:

    Total Density:   890.00/ha     >10 cm:  530.67/ha
    Basal Area:  36.048 sq.m/ha
    Mean Dbh:  17.63 cm, with s.d.  14.33
    Total woody biomass:  253.683 Mg/ha
    Leaf-area index:  6.246
    Average canopy height:  22.7 m


Simulation year:  200

Stand Structure by Species:

  Species Dbh Distribution (#/ha, in 10-cm classes),
```

```
    FRpe  268.7  12.7   4.7   8.0   8.0  4.0   .0   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    ULcr  656.0 118.7  18.0   1.3   2.0  2.0  3.3   .0   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    CEsp  366.7 104.0  22.7  12.0   6.7  2.0  4.0  8.0  3.3   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    QUma   42.7  22.7  20.7   9.3    .7  1.3  2.7  2.7  4.0  2.7
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0
    CAil   14.7    .0    .0    .0   1.3  2.0  2.0  1.3   .0   .0
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

    All: 1348.7 258.0  66.0  30.7  18.7 11.3 12.0 12.0  7.3  2.7
             .0    .0    .0    .0    .0   .0   .0   .0   .0   .0

Species Composition:

  Species Density, Rel. D;   BA, Rel. BA;  IV200; Frequency:

    FRpe      306.0  17.3     3.9  11.6    14.47      .72
    ULcr      801.3  45.3     5.9  17.7    31.52      .97
    CEsp      529.3  30.0    12.7  38.1    34.04      .97
    QUma      109.3   6.2     8.9  26.6    16.42      .81
    CAil       21.3   1.2     2.0   5.9     3.56      .21

Stand Aggregates:

    Total Density:  1767.33/ha     >10 cm:  418.67/ha
    Basal Area:  33.429 sq.m/ha
    Mean Dbh:   9.42 cm, with s.d.  12.34
    Total woody biomass:  277.896 Mg/ha
    Leaf-area index:  6.423
    Average canopy height:  24.5 m
```

ZELIG Output File Z.log (printed at 100-yr intervals)

```
Simulation year:  100

   Growing season begins on day   1.0, ends on 340.4
   and has a total length of 340.4 days.

   Total growing degree-days:  4698.8
   Total precipitation:  105.8 cm
   Total as rain:  105.8 cm
     and as snow:      .0 cm

 Soil water balance for plot (1,1), soil type:    1

   Total annual PET:  146.4     Annual AET:   80.1
   Cumulative runoff:     .0 cm
   Total interception:  19.6 cm
   Dry-days over seedling rooting zone:     .15
   and integrated over all soil layers:    .46
   Dry-days per layer:
         1     .16
         2     .14
         3     .16
         4     .44
         5     .56
         6     .96
         7     .96
         8     .96
         9     .96
        10     .00

 Mortality in plot (1,1), by 10-cm size classes:


      Alive:   1   1   2   1   1   0   0   0   0   0   0   0   0   0   0
      NDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
      SDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

      Total number of trees dead:    0

 Growth factor trace:

   plot (1,1)     Number of trees:    6

       I, Spp, Dbh, Ht, Hc;  ALF, SMF, SFF, DDF, GF;  Dinc, NoGro:

       1 FRpe  20.38 18  8   .71  .29 1.00  .70   .14    .07  0
       2 CAil  35.47 15  9   .60  .00 1.00  .94   .00    .00  1
       3 CEsp  48.70 25  5   .80  .29 1.00  .94   .22    .18  0
       4 ULcr  25.97 15  5   .66  .48 1.00  .68   .22    .18  0
       5 FRpe  12.98 15  8   .65  .29 1.00  .70   .13    .04  0
       6 FRpe   8.07 11  8   .54  .29 1.00  .70   .11    .01  0
```

```
 Regeneration in plot (1,1):

   NPoss: 144   NSStot:   0   NSS:   0
  NPoss2: 144    NStot:   1    NS:   1

      Species, RF; Seedling Cohorts; Sprouts; Saplings:

       1 FRpe   .07     .4   .4   .4   .0              .0   0
       2 ULcr   .14     .7   .6   .7   .3   .2         .0   0
       3 CEsp   .18     .2   .2   .2   .1   .1         .0   0
       4 QUma    .11     .1   .2   .2   .1   .1         .0   0
       5 CAil   .02     .1   .0   .1                  .0   1

      Total number of stems planted:    1

 Light regime for plot (1,1):

   Actual LAI and light profile, from top of canopy:

     25    .11   1.00
     24    .11    .96
     23    .11    .91
     22    .11    .87
     21    .11    .84
     20    .11    .80
     19    .11    .77
     18    .14    .73
     17    .14    .69
     16    .14    .66
     15    .29    .63
     14    .29    .58
     13    .29    .54
     12    .29    .49
     11    .30    .44
     10    .30    .39
      9    .30    .34
      8    .21    .29
      7    .17    .26
      6    .17    .22
      5    .17    .20
      4    .00    .18
      3    .00    .17
      2    .01    .16
      1    .01    .15
      0           .14


Simulation year:  200

   Growing season begins on day   1.0, ends on 365.0
   and has a total length of 365.0 days.
```

```
  Total growing degree-days:  4623.2
  Total precipitation:  260.5 cm
  Total as rain:  260.5 cm
    and as snow:     .0 cm

Soil water balance for plot (1,1), soil type:    1

  Total annual PET:  146.2     Annual AET:   61.2
  Cumulative runoff:    8.7 cm
  Total interception:  86.3 cm
  Dry-days over seedling rooting zone:     .00
  and integrated over all soil layers:    .05
  Dry-days per layer:
       1     .00
       2     .00
       3     .05
       4     .03
       5     .00
       6     .08
       7     .26
       8     .14
       9     .00
      10     .00

Mortality in plot (1,1), by 10-cm size classes:


     Alive:   0   1   2   2   0   0   0   1   0   0   0   0   0   0   0
     NDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
     SDead:   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

     Total number of trees dead:    0

Growth factor trace:

  plot (1,1)     Number of trees:    6

       I, Spp, Dbh, Ht, Hc;  ALF, SMF, SFF, DDF, GF;  Dinc, NoGro:

       1 CAil  75.79 27  9   .54  .90 1.00  .97   .47    .40  0
       2 FRpe  33.54 23  8   .49  .95 1.00  .74   .35    .24  0
       3 FRpe  12.04 14  8   .26  .95 1.00  .74   .18    .05  0
       4 ULcr  23.77 14  3   .25  .96 1.00  .60   .15    .15  0
       5 ULcr  20.21 12  3   .20  .96 1.00  .60   .11    .11  0
       6 QUma  34.30 16  3   .31  .91 1.00  .74   .21    .32  0

Regeneration in plot (1,1):

   NPoss: 144   NSStot:   0   NSS:   0
  NPoss2: 144    NStot:   0    NS:   0
```

```
   Species, RF; Seedling Cohorts; Sprouts; Saplings:

    1 FRpe   .00     .0   .0   .0   .0              .0   0
    2 ULcr   .04     .2   .3   .3   .3   .1         .0   0
    3 CEsp   .06     .1   .1   .1   .1   .0         .0   0
    4 QUma   .05     .0   .0   .0   .1   .0         .0   0
    5 CAil   .00     .0   .0   .0                   .0   0

   Total number of stems planted:    0

Light regime for plot (1,1):

  Actual LAI and light profile, from top of canopy:

     27    .21   1.00
     26    .21    .92
     25    .21    .85
     24    .21    .78
     23    .27    .72
     22    .27    .64
     21    .27    .58
     20    .27    .51
     19    .27    .45
     18    .27    .40
     17    .27    .37
     16    .38    .35
     15    .38    .32
     14    .45    .29
     13    .45    .26
     12    .49    .23
     11    .49    .20
     10    .49    .16
      9    .49    .13
      8    .28    .11
      7    .21    .09
      6    .21    .09
      5    .21    .08
      4    .21    .07
      3    .21    .07
      2    .00    .07
      1    .00    .07
      0           .07
```

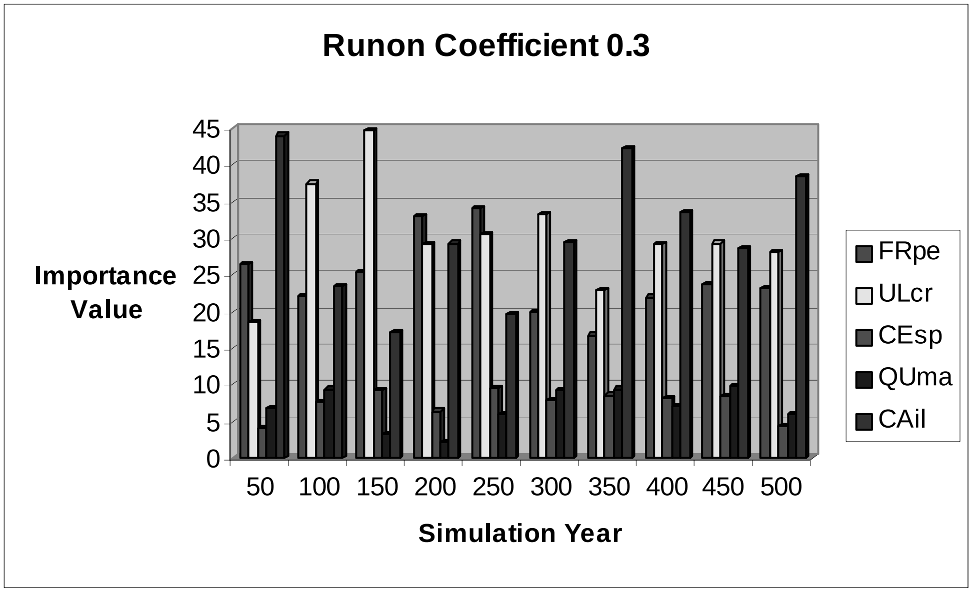
ZELIG Output File Z.tra (printed at 10-yr intervals)

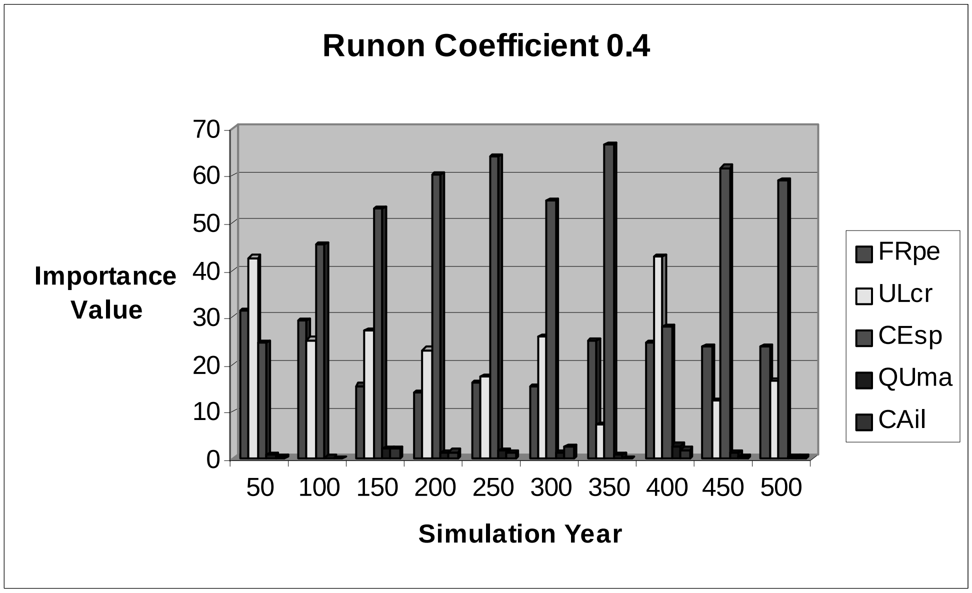
```
  10   3244.00   17.13    2.31    6.88    2.05    8.60    1.28  2.19   .47   .36  2.58
  20   7062.00   83.86    4.88   26.76    7.22   11.11    4.24 11.52  2.62  1.77  6.61
  30   6555.33  131.73   10.71   35.53    6.88   13.43    6.84 14.03  5.13  2.64  6.91
  40   5799.33  162.36   15.22   38.93    7.13   15.38    8.68 13.58  7.15  3.05  6.47
  50   3900.00  187.45   19.45   39.49    7.06   17.10    8.80 11.75  8.74  3.66  6.55
  60   2447.33  202.56   27.06   38.60    6.85   18.43    8.04 11.39  9.89  3.90  5.38
  70   1872.00  225.89   35.62   39.35    6.85   19.88    7.69 10.65 11.66  4.20  5.17
  80   1360.00  236.77   41.27   38.19    6.63   21.05    6.88  9.60 12.39  4.74  4.59
  90   1060.67  250.26   58.41   37.54    6.49   21.95    6.48  8.37 13.31  5.07  4.30
 100    890.00  253.68   69.94   36.05    6.25   22.72    6.10  7.43 13.90  4.93  3.69
 110    958.00  260.29   84.06   35.11    6.09   23.33    5.57  6.84 13.88  5.23  3.60
 120    972.67  270.90   90.25   34.80    6.01   24.26    5.25  6.56 14.32  5.19  3.47
 130   1084.00  281.83  101.99   34.81    6.06   24.74    4.99  6.63 14.20  5.52  3.48
 140   1277.33  277.92  128.09   33.73    5.94   24.79    5.05  5.81 13.56  6.32  2.98
 150   1518.67  286.87  151.09   34.45    6.16   25.10    5.03  5.63 13.65  7.36  2.79
 160   1566.00  291.36  152.19   34.48    6.26   25.43    5.02  5.10 13.71  7.92  2.72
 170   1618.00  288.30  169.83   34.09    6.27   25.33    4.83  4.90 13.81  7.85  2.70
 180   1812.00  287.12  181.11   34.35    6.41   25.18    4.95  5.14 13.44  8.30  2.51
 190   1756.67  295.64  184.76   35.05    6.61   25.14    4.71  5.47 13.19  9.37  2.31
 200   1767.33  277.90  192.29   33.43    6.42   24.47    3.88  5.91 12.75  8.91  1.97
```

APPENDIX E

RUNON EXPERIMENT ADDITIONAL GRAPHS

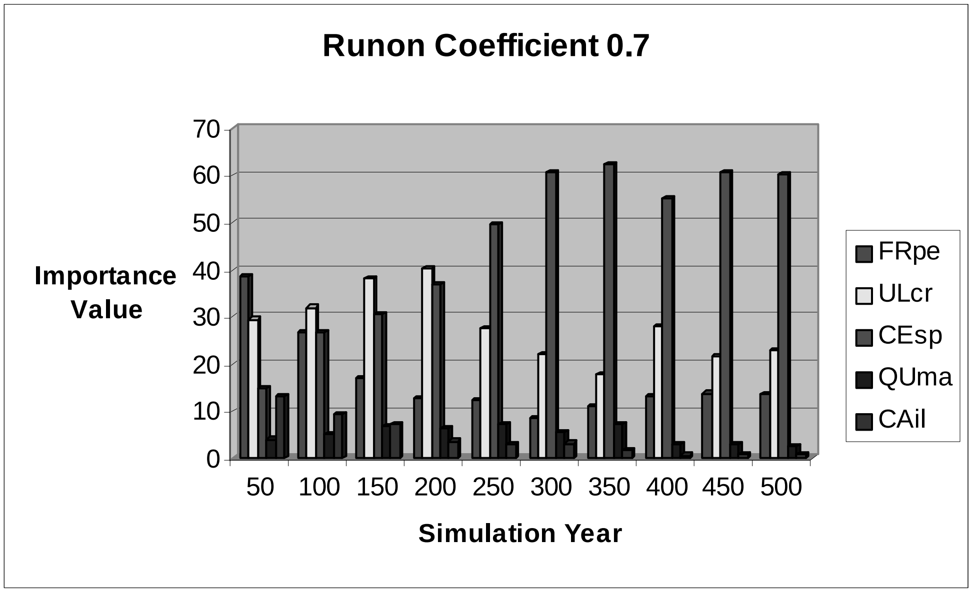
Comparison of Importance Values over Entire Simulation for Significant Runon Coefficients





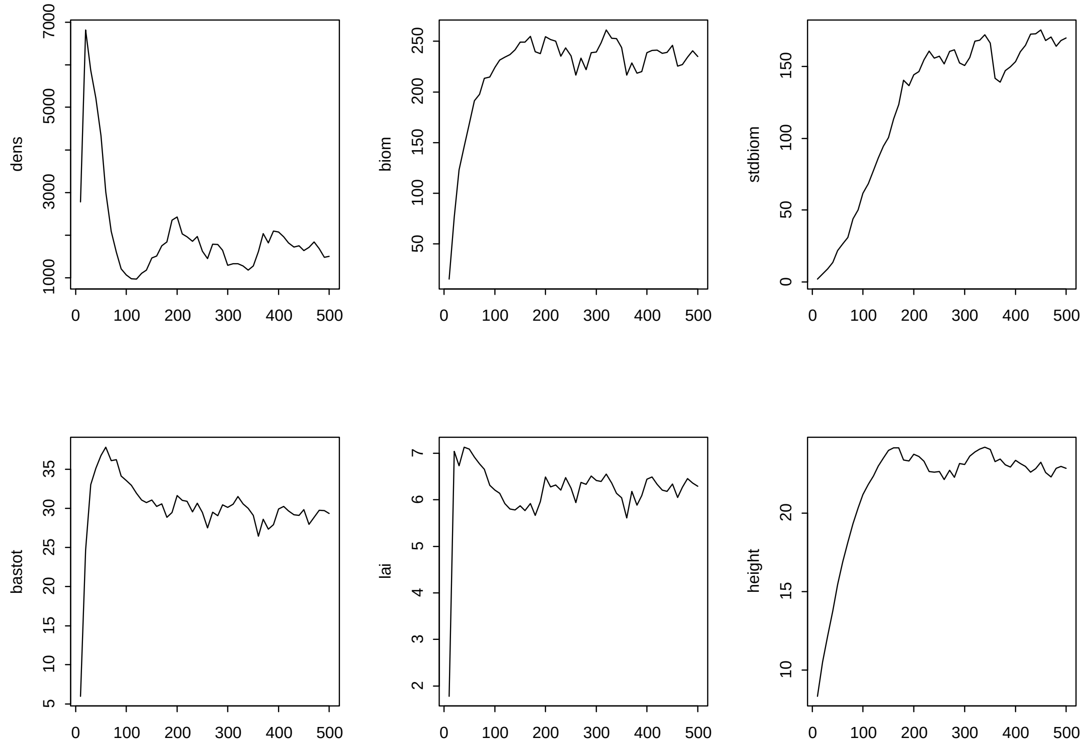
Tree growth of greater than 20 cm dbh was not achieved until the runon coefficient was raised to 0.4. Note the change in species composition between coefficients 0.3 and 0.4.

Best run- runon experiment



Results closest to those found in the Barry and Kroll study (1999) were achieved at year 400, with a runon coefficient of 0.7.

Tracer file graphs for runon experiment, coefficient 0.7



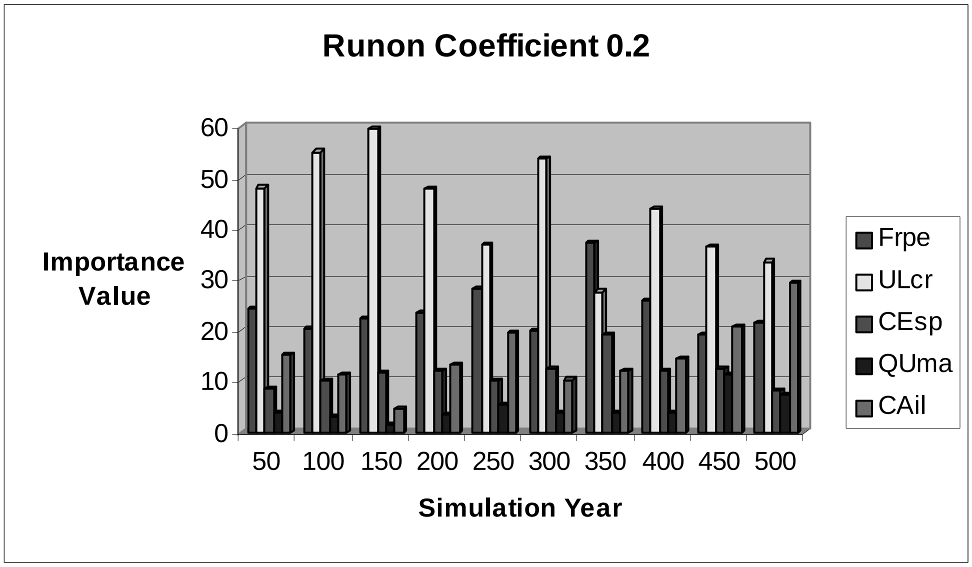
Note that although this run achieved results close to the observed species composition, a large drop remains at around year 350. More experimentation would need to be conducted to discover the reason for this.

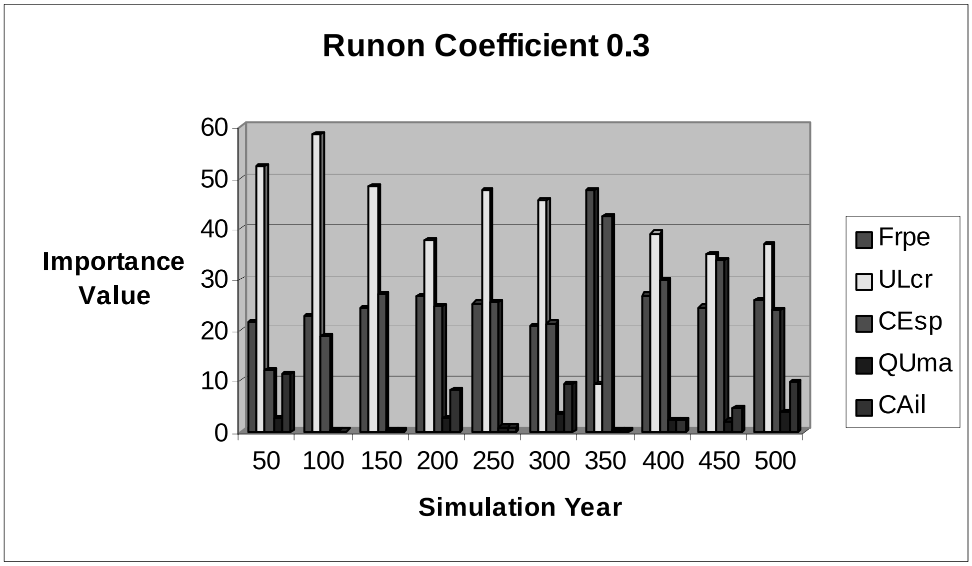
APPENDIX F

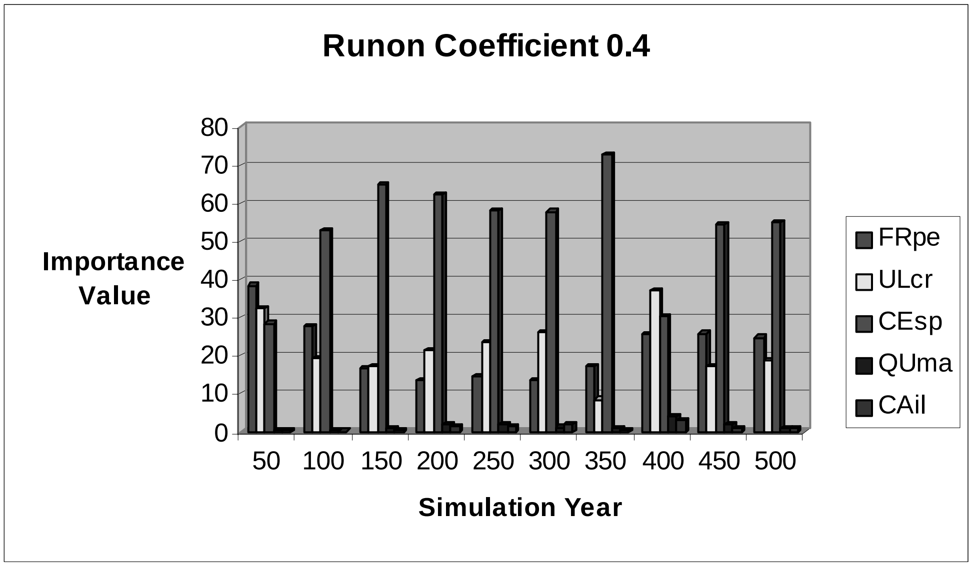
POND EXPERIMENT ADDITIONAL GRAPHS

Comparison of Importance Values over Entire Simulation for Significant Runon Coefficients, With Ponding Function Added

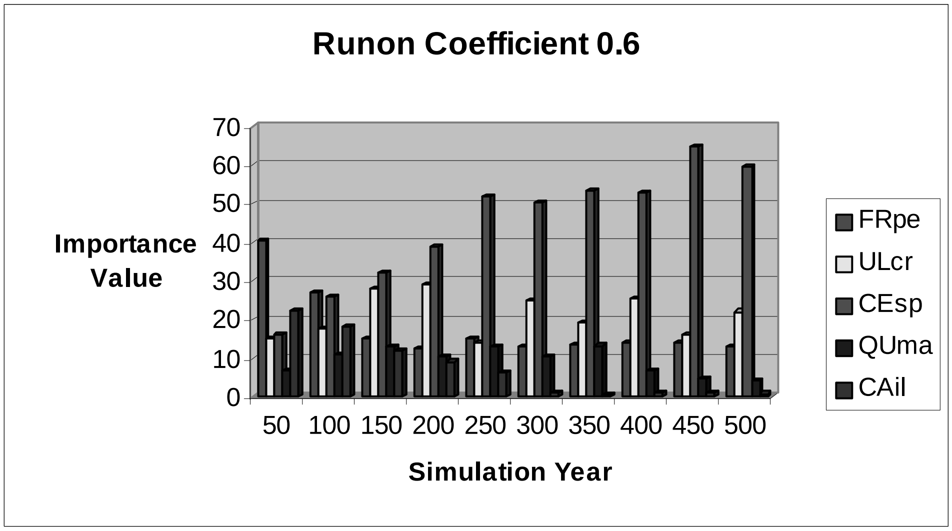
Some tree growth above 20 cm dbh occurred at runon coefficient 0.2 with the ponding function, but consistent tree growth above 20 cm dbh did not occur until the coefficient was raised to 0.4. Thus, the threshold seen in the previous runon experiment was apparent, but not as stark as before.



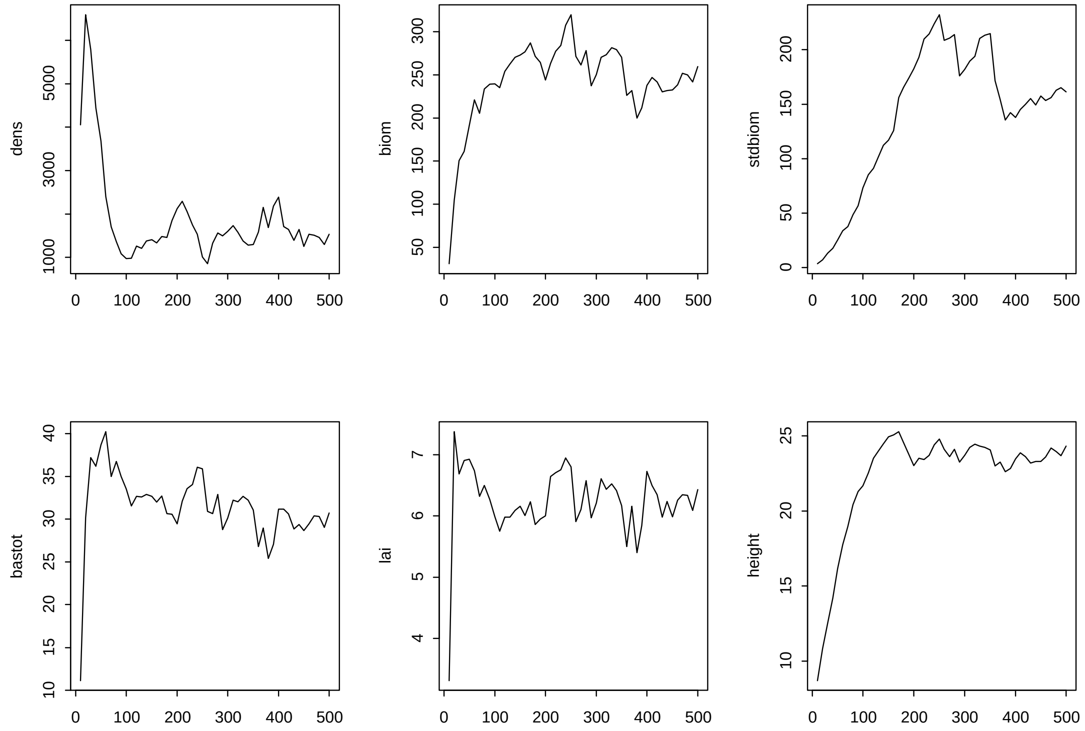




Results closest to those found in the Barry and Kroll study (1999) were achieved at year 400, with a runon coefficient of 0.6, slightly lower than the previous runon experiment.



Tracer File Graphs for Runon Coefficient 0.6



Note that, despite optimal results with regard to species composition and other metrics at 50-year intervals, some oscillations have reappeared in the tracer file graphs. Further experimentation would need to be made to discover the reason for this.

Great Trinity Forest Management Plan

HARDWOOD SILVICULTURE

Sixteen Years of Old-Field Succession and Reestablishment of a Bottomland Hardwood Forest in the Lower Mississippi Alluvial Valley

(Wetlands, Vol. 22, No. 1, March 2002, pp. 1-17)

WETLANDS, Vol. 22, No. 1, March 2002, pp. 1–17

SIXTEEN YEARS OF OLD-FIELD SUCCESSION AND REESTABLISHMENT OF A BOTTOMLAND HARDWOOD FOREST IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY

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Abstract: In the Lower Mississippi Alluvial Valley (LMAV), losses of bottomland hardwood forests have been severe, with less than 30% of the original 10 million ha remaining. Reforestation of abandoned farmland is occurring, but there has been little research on natural reestablishment of these forests. We examined understory succession and tree establishment patterns in a 3.2-ha field in northeast Louisiana, USA, abandoned in 1984. Relative elevation, strongly correlated with flooding depth and frequency, varied by approximately 1m. Ground-layer composition was monitored from 1985 to 1999 in twenty 1-m^2 quadrats stratified along the elevation gradient. In 2000, shrubs and tree saplings were mapped and their relative elevations determined. Ordination of the ground-layer data revealed that the major trends in species composition were related to time-since-abandonment and elevation. Annual species gradually declined, woody perennials became more abundant, and a shrub and young tree layer emerged from beneath the ground layer, but species composition in low and high elevation plots did not converge. Obligate species were more common at lower elevations, while facultative species were more common at upper elevations. By 16 years after abandonment, a total of 16 tree and shrub species had established in the field; eleven of these had potential local seed sources on levees adjacent to the study site. Abundance of dominant species was significantly related to elevation in most cases. In addition, distance to seed source influenced density and spatial distribution of *Celtis laevigata* and *Fraxinus pennsylvanica*. Our study suggests that rate and pattern of secondary succession in LMAV bottomlands are strongly influenced by elevation, dispersal mode of species, and the composition and proximity of forest remnants. Successful restoration of bottomland forests will require an improved understanding of these factors

Key Words: bottomland hardwoods, elevation, floodplain, *Fraxinus pennsylvanica*, Huisman-Olff-Fresco models, hydrologic gradient, Lower Mississippi Alluvial Valley, natural revegetation, old-field, ordination, response curve, succession, wetland forest

INTRODUCTION

The bottomland hardwood forest of the southeastern USA has been called an ‘‘ecosystem in crisis’’ (Creasman et al. 1992). Once extensive along streams and rivers, it has been reduced by conversion to agriculture (MacDonald et al. 1979) and more recently urban development (Sharitz and Mitsch 1993). Remaining forests are often highly fragmented (Creasman et al. 1992) (Figure 1), with diminished ecosystem functioning due to hydrologic alteration and invasion of exotic species (Kellison et al. 1998). Historically, the largest extent of this forest type was in the Lower Mississippi Alluvial Valley (LMAV) (Turner et al. 1981), an area with an estimated 72% loss of the original 10 million ha (Hefner and Brown 1985, Sharitz 1992). In this region, the three states that have sustained the heaviest losses, Arkansas, Mississippi, and Louisiana, still retain the majority of remaining forest cover (Dahl 1990, Dahl and Johnson 1991, Hefner et al. 1994, Dahl 2000). Of the three, Louisiana contains the greatest coverage of bottomland forests, but only approximately 30% of the original 6.5 million ha remain (Dahl 1990, Hefner et al. 1994).

These dramatic losses have prompted restoration

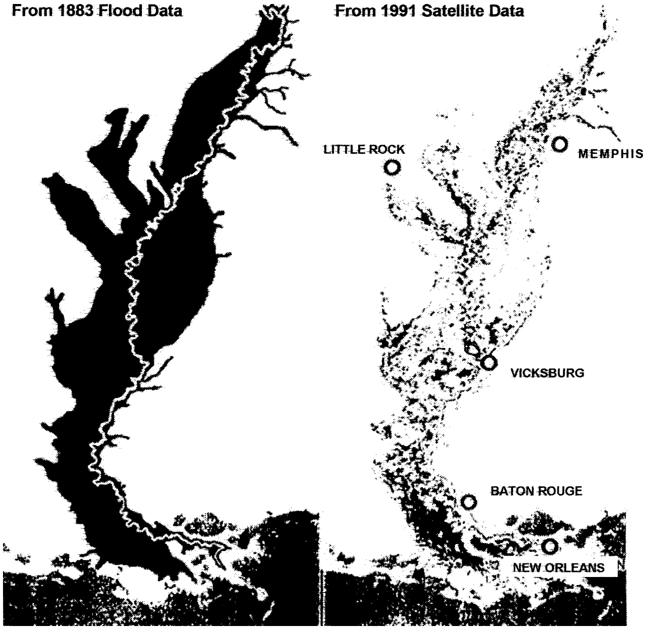

Figure 1. Map of the Lower Mississippi Alluvial Valley (LMAV) showing extent of bottomland hardwood forest fragmentation since 1883. Adapted with permission from The Nature Conservancy of Louisiana.

and conservation efforts (Newling 1990, Sharitz 1992). Many abandoned agricultural areas targeted for restoration are being seeded or planted with seedlings to restore dominance by bottomland species rapidly. Reforestation operations commonly include a limited number of species, mostly oaks, and vary in success (Allen 1990, Allen 1997, Allen et al. 1998, King and Keeland 1999). Some fields have been left fallow, with the expectation that succession will eventually lead to reestablishment of bottomland forest; however, few studies have examined succession (Bonck and Penfound 1945, Hopkins and Wilson 1974, Battaglia et al. 1995) and invasion by tree species in these systems (Allen 1997, Allen et al. 1998). Management decisions would benefit from studies that evaluate natural reestablishment potential. Such studies would also provide information about vegetation development and dynamics in bottomland plant communities.

Paradigms of old-field succession based on upland systems may not apply fully in bottomlands, where hydrology is a primary driver of vegetation dynamics (Robertson et al. 1978, Wharton et al. 1982, Sharitz and Mitsch 1993). Tree regeneration in forested (Jones et al. 1994, Jones and Sharitz 1998, Battaglia et al. 1999) and degraded (DeSteven and Sharitz 1997) floodplains is closely linked to variation in flooding. Thus, the rate and pattern of succession in abandoned bottomlands may differ from upland successions, due, in part, to annual hydrologic fluctuations (Battaglia et al. 1995).

The objectives of this study were 1) to describe patterns of secondary succession along an elevation gradient in a bottomland site, following abandonment of agriculture; 2) to examine patterns of natural tree establishment in relation to elevation and location of seed source; and 3) to highlight aspects of succession that are characteristic of bottomlands in the LMAV.

METHODS

Site Description

This study was conducted in the Ouachita Wildlife Management Area (OWMA), in northeastern Louisiana, USA, at the western edge of the great Mississippi River floodplain. Prior to clearing in the 1960s, this area was covered by bottomland hardwood forest. Until acquisition by the Louisiana Department of Wildlife and Fisheries in 1984, it was planted with sorghum, soybeans, and rice. The landscape is currently a patchwork of small fragments of bottomland forest interspersed with old fields of different times-since-abandonment and restoration stage. After abandonment, some fields were planted with seeds or seedlings of *Carya aquatica*, *C. illinoensis*, *Juglans nigra*, *Quercus laurifolia*, *Q. lyrata*, *Q. michauxii*, *Q. nigra*, *Q. nuttallii*, *Q. phellos*, and *Taxodium distichum* (DePoe and Pritchett 1986). Large saplings of many of these species, particularly the oaks, now dominate these fields (Battaglia, pers. obs.). Nomenclature follows that of Radford et al. (1968). Taxonomic authorities for all names are given in Tables 1 and 4.

A 160 × 200-m study site near Louisiana Highway 15, at 91° 59′ W, 32° 24′ N, was established following abandonment and disking of a soybean field in 1984. The field is periodically inundated following heavy precipitation and backflooding from Bayou Lafourche, a tributary of the Boeuf River, which borders the field on the east. The study site and a buffer zone were left fallow, but the adjacent field was planted with seedlings of native oak species in 1985. See Battaglia et al. (1995) for additional site information.

Field Procedures

A 20 × 20-m grid was established across the field. We used a laser theodolite to measure relative elevation and spatial coordinates at three random points within each grid cell. Repeated measurements showed that elevation and coordinates are accurate to the nearest centimeter. This set of points was used to create a contour map of relative elevation (Figure 2) in SigmaPlot version 4.0 (SPSS Inc. 1997). The elevation range in the field is approximately 1 m.

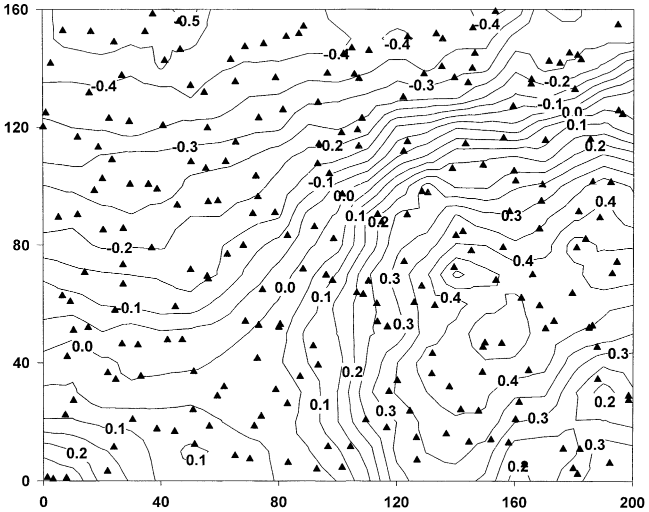

Figure 2. Contour map of the 160 × 200-m study site. Isoclines of relative elevation were generated in SigmaPlot version 4.0 and are based on 240 surveyed points (filled triangles).

Twenty permanent 1-m^2 quadrats, spanning the elevation gradient, were established in 1985 (Year 1) (Battaglia et al. 1995). Relative elevations at the southwest corner of each quadrat ranged from -0.53 to 0.40 m. In August 1985–1989 (Years 1–5), 1994 (Year 10), and 1999 (Year 15), projected foliage cover of each species in these plots was estimated to the nearest 1%. To eliminate variation among observers, estimates were always made by the same person (D. W. P.).

In May–June 2000, individuals ≥1 m in height of all trees and the multi-stemmed shrub, *Cephalanthus occidentalis*, were tagged, identified to species, and mapped using a laser theodolite. The relative ground elevation at the base of each individual sapling or center of each *C. occidentalis* clone was also measured. For tree saplings, we measured height of the tallest foliage and the diameter of each stem at 30 cm above ground. Only height was measured for *C. occidentalis*. The density of *Fraxinus pennsylvanica* was so great that we measured only a sample of the individuals. A stratified random procedure was used to select 379 of the 787 *F. pennsylvanica* saplings (48%) for measurement.

The multi-stemmed shrub, *Baccharis halimifolia*, was too abundant for tagging individual stems and too large and patchily distributed to be adequately sampled in the small permanent plots. In May 2000, we estimated its cover in twenty 100-m^2 circular plots centered on each of the permanent cover quadrats.

The nearest seed sources of tree species were located approximately 10 m from the northern and southern borders, along two small levee systems. The levees are roughly parallel to the site boundaries. We surveyed each levee community in July 2000 and recorded species with at least one large and presumably reproductive individual present.

Data Analyses

To examine trends in species composition in the permanent plots, we used non-metric multidimensional scaling (NMDS), a technique that has been shown to be robust and effective for ordination of community data (Minchin 1987). NMDS finds an ordination of quadrats in a specified number of dimensions, such that the distances among all pairs of quadrats in the ordination are, as far as possible, in rank-order agreement with compositional dissimilarities among the quadrats. Starting from an initial ordination, the positions of quadrats are gradually adjusted in order to minimize ''stress,'' a measure of the badness-of-fit of a rank-order regression of ordination distances on dissimilarities. The percentage cover data were standardized by species maxima, and dissimilarities were calculated using the Bray-Curtis index (Bray and Curtis 1957). This combination of standardization and dissimilarity index is one of the most effective for community ordination (Faith et al. 1987, Sandercock 1997). We performed NMDS in one to six dimensions, in each case using 10 random initial configurations.

Vector fitting (Dargie 1984, Faith and Norris 1989, Kantvilas and Minchin 1989) was used to examine patterns of correlation between the ordination and explanatory variables. Vector fitting is a form of multiple linear regression that finds the direction across the ordination along which sample coordinates have maximum correlation with the fitted variable. Statistical significance of the correlation is tested by randomly permuting the values of the variable among quadrats, simulating the null hypothesis of no trend. Ordinations, vector fitting, and related data manipulations were performed using the DECODA package (Minchin 1989).

Distribution maps were plotted for each of the tree and shrub species surveyed in May–June 2000. Frequency histograms of height and diameter at 30 cm above ground were created for each species. For multi-stemmed individuals (particularly common in *Ilex decidua* and *Crataegus viridis*), we first computed the total basal area of all stems, then calculated the diameter of an equivalent single stem of the same basal area. Overall density and basal area per hectare were computed for each tree species (density only for the shrub *C. occidentalis*). For *F. pennsylvanica*, mean basal area per individual was computed for those individuals that were measured, and basal area per hectare was calculated by assuming the same mean for the unmeasured individuals.

Response curves of species to elevation were fitted using Huisman-Olff-Fresco (HOF) models (Huisman et al. 1993, Oksanen 1997). HOF models are particularly useful for modeling response curves in that they can accommodate the monotonic, symmetric unimodal, ''plateau'' and skewed unimodal shapes that have been observed in direct gradient studies (Austin and Gaywood 1994). The models were fitted using nonlinear maximum likelihood methods with a Poisson error distribution and adjustments for overdispersion. Starting with the ''full'' model, which allows for a skewed unimodal response, backwards elimination was used to determine the appropriate response shape for each species, with the p value for significance of the change in deviance set at 0.05. HOF modeling was conducted using the program by Oksanen (1996).

For tree species, HOF models were fitted for both density and basal area. A density model was also fitted for the shrub *C. occidentalis*. Density and basal area were computed in each 0.1-m elevation class between −0.5 m and 0.5 m. The proportion of surveyed random points falling into each elevation class was used as an estimate of the proportion of the total area of the field in that class. These proportions were then used to adjust raw counts of numbers of individuals or total basal area in each class to density or basal area per hectare.

The spatial distributions of *C. laevigata* and *F. pennsylvanica* suggested that both elevation and distance from closest seed source (the levee systems running parallel to the southern and northern margins of the field) may have influenced their densities. The field was divided into sixteen 10 × 200 m strips parallel to its long axis, and density was tallied for each species in each strip. Prevailing winds are from the southwest, so distance of each strip from the southern edge of the field was estimated for the wind-dispersed *F. pennsylvanica* recruits. Minimum distance of each strip from either the southern or northern edge of the field was estimated for the bird/mammal- dispersed *C. laevigata*. General non-linear modeling software (SAS Institute Inc. 1989: Procedure NLIN) was used to fit models for density as a function of distance. The fitted model for *F. pennsylvanica* was of the form

$$y = ae^{-bx^c} + d$$

where y is density, x is distance from edge, and a, b, c, and d are fitted parameters. For *C. laevigata*, a simpler model was found to be sufficient, leaving out the parameter d.

The wetland indicator status of each species observed in the field was determined using the system developed by the United States Department of Agriculture (United States Department of Agriculture 2001).

RESULTS

Understory Succession

Examination of changes in mean cover among years (Table 1) shows a shift toward dominance by perennial species. The majority of annual taxa attained peak cover during the early years of succession; gradually, they were overtaken by herbaceous and woody perennial species. In the first few years following abandonment, many annual species (*e.g.*, *Digitaria sanguinalis*, *Sesbania macrocarpa*, and *Sida spinosa*) and a few perennial species (*e.g.*, *Amaranthus arenicola* and *Rumex crispus*) peaked in abundance. Most of these early colonists are weed species, considered to be common pests in soybean fields, and had declined or disappeared by Year 5. In Year 5, several herbaceous perennial species became established (*e.g.*, *Andropogon virginicus*, *Cyperus pseudovegetus*, and *Solidago canadensis*) that would persist through Year 15. Most of the early perennial invaders were herbaceous, although *Campsis radicans*, a woody vine, maintained high cover values throughout the study, particularly at higher elevations. By Year 15, woody taxa were more abundant throughout the field. Three tree species (*Crataegus viridis*, *Fraxinus pennsylvanica*, *Ilex decidua*) were recorded in the 1-m^2 permanent plots. The shrub, *Baccharis halimifolia*, gradually increased in cover over the study period.

The two-dimensional NMDS ordination (stress = 0.27, achieved from four of the ten random starts) was accepted as an adequate summary of the permanent quadrat data (Figure 3). Reductions in stress with increasing dimensions were gradual and modest (stress in 3D = 0.20), and additional dimensions had no clear ecological interpretation. Fitted vectors of maximum correlation for year ($r = 0.82$) and elevation ($r = 0.65$) were both highly significant ($p < 0.001$), and the angle between the vectors was 89°, so these vectors represent two independent trends in species composition, summarized by Tables 2 and 3.

The year trend (Table 2) corresponds closely with the pattern observed in Table 1 and outlined above. This is to be expected, given the high correlation between this floristic dimension and year. The pattern of change in composition among years was examined by plotting the trajectory of the centroids of the quadrats in each year (Figure 3). This was done separately for the subsets of quadrats at lower elevations (≤ 0.0 m) and higher elevations (> 0.0 m). The trajectories of the subsets are generally parallel and broadly in the direction of the year vector, indicating an overall trend of directional succession in both lower and higher elevation sites, but some anomalies are apparent. In lower elevation quadrats, the directions of change from 1985 to 1986 and from 1986 to 1987 are virtually perpen-

Table 1. Average percent cover of species in 20 permanent 1-m^2 quadrats over a 15-year period following field abandonment in 1984. Cover was estimated in August 1985–1989, 1994, and 1999 and averaged over the 20 plots in each sampling year. Wetland indicator status, where available, is given for each taxon (OBL = obligate wetland; FACW = facultative wetland; FAC = facultative; FACU = facultative upland) (United States Department of Agriculture 2001). Annual, biennial, and perennial growth forms are coded using A, B, and P, respectively. Additionally, grasses, herbs, shrubs, trees, and vines are coded using G, H, S, T, and V, respectively. Generic names are given in cases where neither sexual nor species-specific vegetative structures were found. Voucher specimens are stored in the herbarium at the University of Louisiana—Monroe.

Species	1985	1986	1987	1988	1989	1994	1999	Wetland Status	Growth Form
Alternanthera philoxeroides (Martius) Grisebach	0.35	0.25	0.14	0.05	0.04	0.01	—	OBL	PH
Amaranthus arenicola I. M. Johnston	0.50	0.04	—	—	0.02	—	—	FACU	PH
Ambrosia trifida L.	—	—	—	—	0.10	—	—	FAC	AH
Ampelopsis arborea (L.) Koehne	—	—	—	—	—	0.20	—	FAC+	PV
Andropogon virginicus L.	—	—	—	0.68	4.39	1.83	0.55	FAC−	PG
Aster spp.	0.48	17.63	0.25	0.72	2.38	2.29	1.52	—	AH/PH
Baccharis halimifolia L.	0.30	1.00	0.08	0.26	—	0.35	3.38	FAC	PS
Berchemia scandens (Hill) K. Koch.	—	—	—	—	—	—	0.20	FACW	PV
Brunnichia ovata (Walt.) Shinners	3.18	1.10	3.41	1.24	3.39	7.31	1.52	FACW	PV
Campsis radicans (L.) Seemann	7.85	12.42	16.75	16.55	14.56	14.03	4.43	FAC	PV
Cardiospermum halicacabum L.	0.13	—	—	—	—	0.20	0.10	FAC	AH
Carex verrucosa Muhl.	—	0.34	2.45	0.01	0.08	—	0.35	OBL	PH
Conyza canadensis (L.) Cronq.	0.03	1.70	0.13	—	0.04	0.45	—	FACU	AH
Crataegus viridis L.	—	—	—	—	—	—	0.13	FACW	PT
Cyperus pseudovegetus Steudel.	—	—	—	—	0.01	0.14	0.71	FACW	PH
Desmanthus illinoensis (Michaux) MacM.	0.05	0.70	0.47	3.20	2.47	17.74	6.84	FAC	PH
Digitaria sanguinalis (L.) Scopoli.	—	—	0.14	—	0.03	—	—	FAC−	AG
Diodia virginiana L.	0.01	0.14	—	—	—	—	—	FACW	PH
Eclipta alba (L.) Hasskarl.	—	—	—	0.45	0.02	—	—	FACW−	AH
Elymus virginicus L.	—	—	—	—	—	0.05	0.09	FAC	PG
Euphorbia spp.	1.06	0.34	1.28	0.03	0.08	—	—	—	AH
Fraxinus pennsylvanica Marshall	—	—	—	—	—	—	0.21	FACW	PT
Galium tinctorium L.	—	—	—	—	<0.01	0.05	—	FACW	AH
Gnaphalium purpureum L.	—	0.02	0.30	—	—	—	—	UPL	AH
Ilex decidua Walter	—	—	—	—	—	—	0.02	FACW−	PT
Ipomoea spp.	4.78	0.81	1.49	0.12	0.47	0.09	—	—	AV
Iva annua L.	—	1.18	2.59	9.28	0.69	3.18	1.78	FAC	AH
Juncus spp.	—	—	0.01	0.10	0.46	0.29	0.07	—	PH
Krigia dandelion (L.) Nuttall	—	—	—	0.50	—	0.03	—	FACU	PH
Lathyrus hirsutus L.	—	—	—	—	0.01	0.35	—	?	AV
Leptochloa filiformis (Lam.) Beauvois	0.78	—	0.15	—	—	—	—	FACW	AG
Ludwigia spp.	—	—	—	—	0.08	0.99	—	OBL	AH/PH
Lythrum alatum Pursh.	—	—	—	—	—	0.03	0.16	FACW+	PH
Mimosa strigillosa Torr. and Gray	—	—	—	—	—	—	0.01	FAC	PH
Oenothera biennis L.	0.69	—	—	0.05	—	—	—	FACU	BH
Oenothera laciniata Hill	0.10	—	—	—	—	—	—	FACU	AH

Table 1. Continued.

Species	1985	1986	1987	1988	1989	1994	1999	Wetland Status	Growth Form
Oxalis debilis var. *corymbosa* (DC.) Lourteig	0.04	0.30	0.03	—	0.03	—	—	?	AH
Panicum dichotomum L.	—	—	—	—	—	—	0.08	?	PG
Phalaris caroliniana (Walter)	—	—	—	—	—	0.12	—	FACW	AG
Phyla lanceolata (Michaux) Greene	—	—	—	—	—	0.17	—	FACW+	PH
Polygonum spp.	4.90	—	0.04	0.04	0.15	0.32	0.03	OBL	AH
Portulaca oleracea L.	0.01	—	—	—	—	—	—	FACU	AH
Pyrrhopappus carolinianus (Walter) DC.	—	0.09	0.03	0.11	0.18	0.08	—	?	AH
Ranunculus sardous Crantz	0.14	0.31	2.68	1.68	0.40	0.94	—	FAC+	AH
Rorippa palustris (L.) Bess	0.15	—	—	—	—	—	—	OBL	AH
Rubus trivialis Michaux	—	—	—	—	0.07	0.59	2.53	FAC	PV
Rumex crispus L.	1.03	0.06	—	0.01	0.06	—	—	FAC	PH
Sesbania macrocarpa Muhl. ex Raf.	0.41	0.03	13.45	0.03	0.81	—	0.08	FACW−	AH
Setaria geniculata (Lam.) Beauvois	—	—	—	—	0.06	—	—	FAC	PG
Sida spinosa L.	0.39	1.07	2.30	0.16	1.35	0.02	—	FACU	AH
Smilax bona-nox L.	—	—	—	—	—	—	0.02	FAC	PV
Solanum carolinense L.	0.49	0.30	0.40	0.20	0.14	0.04	—	FACU	PH
Solidago canadensis L.	—	—	—	—	3.84	0.58	0.80	FACU	PH
Sorghum halepense (L.) Persoon	0.21	1.11	0.82	0.18	0.61	0.09	—	FACU	PG
Spermacoce glabra Michaux	—	—	—	—	—	—	0.58	FACW	PH
Spiranthes spp.	—	—	—	—	—	0.02	—	?	PS
Trachelospermum difforme (Walter) Gray	—	—	—	—	—	—	0.10	FACW	PV
Verbena brasiliense Vellozo	—	—	—	—	—	0.04	—	?	PH

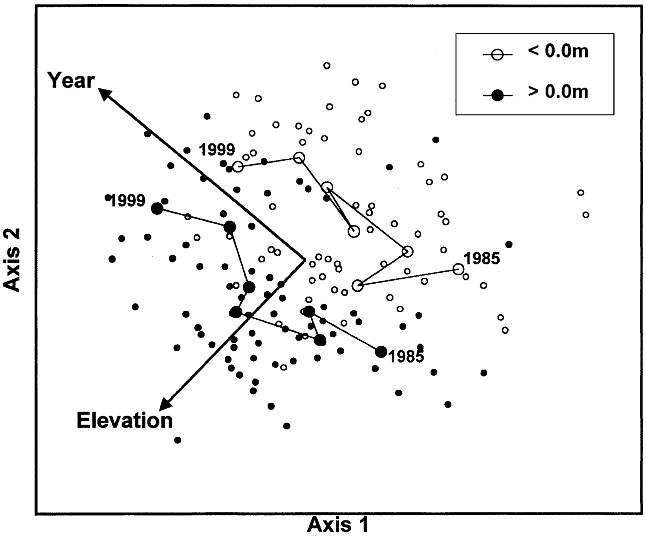

Figure 3. Two-dimensional NMDS ordination (stress = 0.27) of the 20 permanent 1-m^2 quadrats, based on cover data standardized by species maxima and using the Bray-Curtis dissimilarity index. Fitted vectors are shown for year (r = 0.82, p < 0.001) and elevation (r = 0.65, p < 0.001). These are virtually perpendicular (angle = 89°). Vector lengths are proportional to correlations. The trends in species composition represented by the vectors are summarized in Tables 2 and 3. Time trajectories are shown separately, using the centroids in each year, for quadrats above (filled circles) and below (hollow circles) 0.0m relative elevation. Centroids are joined in order of sampling year: 1985, 1986, 1987, 1988, 1989, 1994, and 1999. The smaller symbols show the coordinates of individual quadrats in each year.

Table 2. Mean cover of species in 10 segments along the fitted vector for year in the NMDS ordination. The data were standardized by species maxima and rounded into 10 classes, with upper limits of 0.1, 0.2, 0.3, . . . , 0.9 and 1.0 (represented by X). Dashes (--) indicate absence. The species are ordered according to their weighted mean coordinates along the year vector. The table summarizes the compositional trend represented by the year vector.

Portulaca oleracea	X---------
Oenothera laciniata	X---------
Oenothera biennis	X-----1---
Rorippa palustris	-X--------
Rumex crispus	X612111---
Alternanthera philoxeroides	X-8---11--
Amaranthus arenicola	XX3511----
Leptochloa filiformis	4X23------
Polygonum spp.	X91411111-
Ipomoea spp.	9X631111--
Carex verrucosa	X1-1111111
Euphorbia spp.	44X41111--
Sesbania macrocarpa	1X6421-1--
Diodia virginiana	--XX------
Digitaria sanguinalis	-XX55-----
Solanum carolinense	-X13311-1-
Sida spinosa	25X5611---
Sorghum halepense	71X862211-
Aster spp.	-1XX761242
Krigia dandelion	----X-11--
Conyza canadensis	--X25414--
Ranunculus sardous	1422X2231-
Setaria geniculata	----XX----
Gnaphalium purpureum	----X1----
Oxalis debilis	-5--1X1---
Campsis radicans	--286X5211
Pyrrhopappus carolinianus	6--X55249-
Brunnichia ovata	-71525X521
Cardiospermum halicacabum	-X--1-39--
Juncus spp.	---13X4834
Iva annua	--1133X644
Eclipta alba	----11X1--
Andropogon virginicus	---113X343
Ludwigia spp.	----118X--
Phalaris caroliniana	------X14-
Ampelopsis arborea	-----28X--
Galium tinctorium	-----36X--
Rubus trivialis	----1812X2
Phyla lanceolata	------5X--
Fraxinus pennyslvanica	-----4--X1
Desmanthus illinoensis	-11-116X21
Solidago canadensis	----112X61
Baccharis halimifolia	-22111114X
Lathyrus hirsutus	----1--2X-
Cyperus pseudovegetus	----1-13X2
Elymus virginicus	------25-X
Lythrum alatum	-------92X
Verbena brasiliense	--------X-
Berchemia scandens	--------X-
Crataegus viridis	--------X-
Spermacoce glabra	-----1-1-X
Panicum dichotomum	---------X
Trachelospermum difforme	---------X
Ilex decidua	---------X
Mimosa strigillosa	---------X

dicular to the year vector and suggest a shift toward composition more typical of higher elevation sites in 1986, then a reversion toward lower elevation species in 1987. Lower elevation sites seem to have undergone a reversal, relative to the overall trend, between 1988 and 1989. In the upper elevation sites, the degree of change between years is relatively small between 1986 and 1987 and again between 1988 and 1989. The total amount of compositional change (length of trajectory) is similar in lower and higher elevation subsets. In both subsets, succession was more rapid during the first five years than in the final ten years.

The correlation of the other dimension of the ordination with elevation underlines the importance of ecological factors associated with elevation in determining the species composition of the vegetation within years. Throughout the study, a clear trend in composition was evident along the elevation gradient (Figure 3). Species appeared, disappeared, and some species distributions shifted, expanded, or contracted with time, so that beta diversity along the elevation gradient varied among years. In general, obligate and facultative-wetland species were more common at lower el-

Table 3. Mean cover of species in 10 segments along the fitted vector for elevation in the NMDS ordination. The data were standardized by species maxima and rounded into 10 classes, with upper limits of 0.1, 0.2, 0.3, . . . , 0.9 and 1.0 (represented by X). Dashes (-) indicate absence. The species are ordered according to their weighted mean coordinates along the year vector. The table summarizes the compositional trend represented by the elevation vector.

Rorippa palustris	X---------
Gnaphalium purpureum	X--1------
Eclipta alba	X3-1-1----
Setaria geniculata	-X-6------
Ludwigia spp.	X161-111--
Amaranthus arenicola	615X------
Leptochloa filiformis	X1X--12-11
Iva annua	X733211111
Sesbania macrocarpa	1XX111111-
Ampelopsis arborea	-X6-22-2--
Polygonum spp.	X2321111-4
Digitaria sanguinalis	X96-84-3--
Cardiospermum halicacabum	3X9-2-512-
Ranunculus sardous	1X31231211
Juncus spp.	1X42124111
Sida spinosa	1XX3354211
Brunnichia ovata	6X36257111
Cyperus pseudovegetus	--X541214-
Spermacoce glabra	--1X-3-2--
Ipomoea spp.	1X36355111
Phalaris caroliniana	2-1-X1-4--
Desmanthus illinoensis	1185X44661
Euphorbia spp.	-54156X411
Conyza canadensis	62142412X2
Carex verrucosa	-1311x3112
Andropogon virginicus	--2X322135
Rumex crispus	---53X62-1
Aster spp.	1117958X62
Elymus virginicus	----4XXX--
Baccharis halimifolia	142131-X41
Pyrrhopappus carolinianus	---262X882
Campsis radicans	1111146X76
Solanum carolinense	-1---3919X
Rubus trivialis	----12326X
Solidago canadensis	---211213X
Sorghum halepense	11-1111-3X
Fraxinus pennsylvanica	-------1X8
Ambrosia trifida	---------X
Crataegus viridis	---------X
Krigia dandelion	----11-1-X

evations, while facultative and facultative-upland species were more common at upper elevations. *Cyperus pseudovegetus*, a facultative-wetland species that was absent in 1985–1988, established in the lowest elevation plot in 1989. By 1994, it had expanded to five low- to mid-elevation plots and one high-elevation plot. In 1999, we recorded this species in 12 plots spanning most of the elevation gradient. In the first few years of succession, occurrence of *Desmanthus illinoensis*, a facultative legume, was limited to a few plots of intermediate elevation. Over time, it expanded toward both lower and higher elevations; it was observed in seven plots in 1989, 16 in 1994, and 18 in 1999. *Rubus trivialis*, a facultative vine species absent in the first four years, had established in three upper elevation plots by 1989 and four in 1994. By 1999, its abundance was high, and it had expanded into a total of seven upper elevation plots. In 1994, lower elevation plots were dominated by *Brunnichia ovata* and contained a mixture of herbaceous taxa with low abundance (*e.g.*, *Ludwigia* spp. and *Iva annua*). *Campsis radicans* was abundant throughout the gradient. Several species, including *Andropogon virginicus*, *Rubus trivialis*, and *Solidago canadensis*, were restricted to higher elevations. By 1999, the vines, *B. ovata* and *C. radicans*, had decreased in abundance, and *A. virginicus* occupied most sections of the gradient. *Baccharis halimifolia*, *R. trivialis*, *S. canadensis*, and seedling establishment of tree species (*F. pennsylvanica*, *C. viridis*, *I. decidua*) were limited to the upper elevation plots. In general, these shifts in species composition along the elevation gradient were gradual, and there were no clear community discontinuities.

Dissimilarity between lower and higher elevation plots was lowest in 1986. Rainfall data from the University of Louisiana at Monroe station showed that 1986 was the driest year in which we sampled the permanent plots (National Oceanic and Atmospheric Administration 2001). The decrease in dissimilarity was driven primarily by changes in the distribution of *Aster* spp., a taxon typically more abundant in upper elevation areas (Table 3). In 1986, however, it also dominated the lower plots and occurred in 19 of the 20 plots, contributing to its overall peak in this dry year. This expansion was temporary, as *Aster* spp. occurred in only four plots in 1987. Its frequency increased again in 1988–1989. By 1994, its abundance had increased, and it was found in 15 plots. By 1999, it had reoccupied the lower plots, but unlike in 1986, low and high elevation plots did not become more similar due to their discrimination at that time by other species.

Woody Species Establishment

By May 2000, a total of sixteen species of trees and shrubs had established in the field. Eleven of these had potential local seed sources on one or both of the levee systems that parallel the southern and northern edges of the study site (Table 4).

Total density of all tree species and the shrub *Cephalanthus occidentalis* was 497 ha^{-1}. The total basal area of all tree species was 0.71 m^2 ha^{-1} (Table 5).

Table 4. Primary dispersal mechanisms and occurrence of shrub and tree species in the study site and adjacent levee communities (Radford et al. 1965, McKnight et al. 1981). ''B'' = bird, ''G'' = gravity, ''M'' = mammal, and ''W'' = wind; ''+'' = present and ''−'' = absent. Presence of each species on the levees is noted only if large and presumably reproductive individuals are present.

Species	Dispersal Agent	Present in Site	South Levee	North Levee
Acer negundo L.	B, M, W	−	+	−
Acer rubrum L.	B, M, W[1]	+	−	−
Baccharis halimifolia L.	W	+	−	−
Carya aquatica (Michaux f.) Nuttall	B, G, M[1]	+	+	+
Celtis laevigata Willd.	B, M[1]	+	+	+
Cephalanthus occidentalis L.	W[1]	+	+	+
Crataegus viridis L.	B, M	+	+	+
Diospyros virginiana L.	B, M	+	+	+
Forestiera acuminata (Michaux) Poiret	B[1]	−	+	+
Fraxinus pennsylvanica Marshall	W[1]	+	+	−
Gleditsia triacanthos L.	B, M, W[1]	+	+	+
Ilex decidua Walter	B, M	+	+	+
Liquidambar styraciflua L.	W	+	−	−
Planera aquatica Walter ex J. F. Gmelin	B, M[1]	−	−	+
Populus deltoides Marshall	W[1]	−	+	−
Quercus lyrata Walter	B, G, M[1]	−	+	+
Quercus nigra L.	B, G, M[1]	+	−	−
Quercus phellos L.	B, G, M[1]	−	+	−
Salix nigra Marshall	W[1]	+	+	+
Sideroxylon lycioides L.	B	+	−	−
Ulmus crassifolia Nuttall	W[1]	+	+	−
Ulmus americana L.	W[1]	+	+	−
Ulmus rubra Muhl.	W[1]	−	+	−

[1] May be secondarily dispersed by water.

Table 5. Mean height, density, and basal area of invading shrub and tree species in OWMA study site. Total density = 497 ha^{-1}. Total basal area = 0.71 m^2 ha^{-1}. The shrub *Baccharis halimifolia* is not included in these data.

Species	Mean Height ± s.d. (m)	Density (ha^{-1})	Basal Area (m^2 ha^{-1})
Acer rubrum	1.30*	0.31	0.00002
Carya aquatica	5.73 ± 1.52	1.56	0.034
Celtis laevigata	2.56 ± 1.12	36.25	0.042
Cephalanthus occidentalis	2.39 ± 0.71	57.19	—†
Crataegus viridis	2.23 ± 0.84	32.81	0.028
Diospyros virginiana	2.32 ± 0.96	17.81	0.017
Fraxinus pennsylvanica	2.97 ± 1.48	245.00	0.390
Gleditsia triacanthos	1.90 ± 0.92	5.00	0.0023
Ilex decidua	2.84 ± 0.83	50.63	0.076
Liquidambar styraciflua	0.85 ± 0.57	0.63	0.00059
Quercus nigra	3.12 ± 0.14	0.94	0.00141
Salix nigra	3.50*	0.31	0.00030
Sideroxylon lycioides	3.20*	0.31	0.00039
Ulmus crassifolia	3.08 ± 0.78	40.00	0.095
Ulmus americana	2.96 ± 1.97	7.19	0.018

* Only one individual recorded.
† Diameters not measured.

Fraxinus pennsylvanica was by far the most dominant tree species, both in terms of density and basal area, and accounted for approximately half of all stems and more than half of the total basal area in the field. Its abundance was over four times greater than that of *C. occidentalis*, the species with the second greatest density, and *Ulmus crassifolia*, the species with the second greatest basal area. Other species, abundant in either or both density and basal area, included *Ilex decidua*, *Celtis laevigata*, *Crataegus viridis*, *Ulmus americana*, *Diospyros virginiana*, *Gleditsia triacanthos*, and *Carya aquatica* (Table 5).

Distribution patterns in the field varied by species (Figure 4). Although abundant, *F. pennsylvanica* was not ubiquitous. This wind-dispersed tree was most common along the southern edge of the site and was sparse in the interior part of the field, particularly at higher elevations. *Celtis laevigata*, a species dispersed by birds and small mammals, showed a similar pattern of greater density near the southern edge of the site and also had a relatively high density along the northern edge. *Crataegus viridis* and *Ilex decidua*, both primarily bird-dispersed species, spanned the field from north to south but were concentrated in the eastern half, *I. decidua* being particularly dense in the southeastern corner. *Diospyros virginiana*, which has large

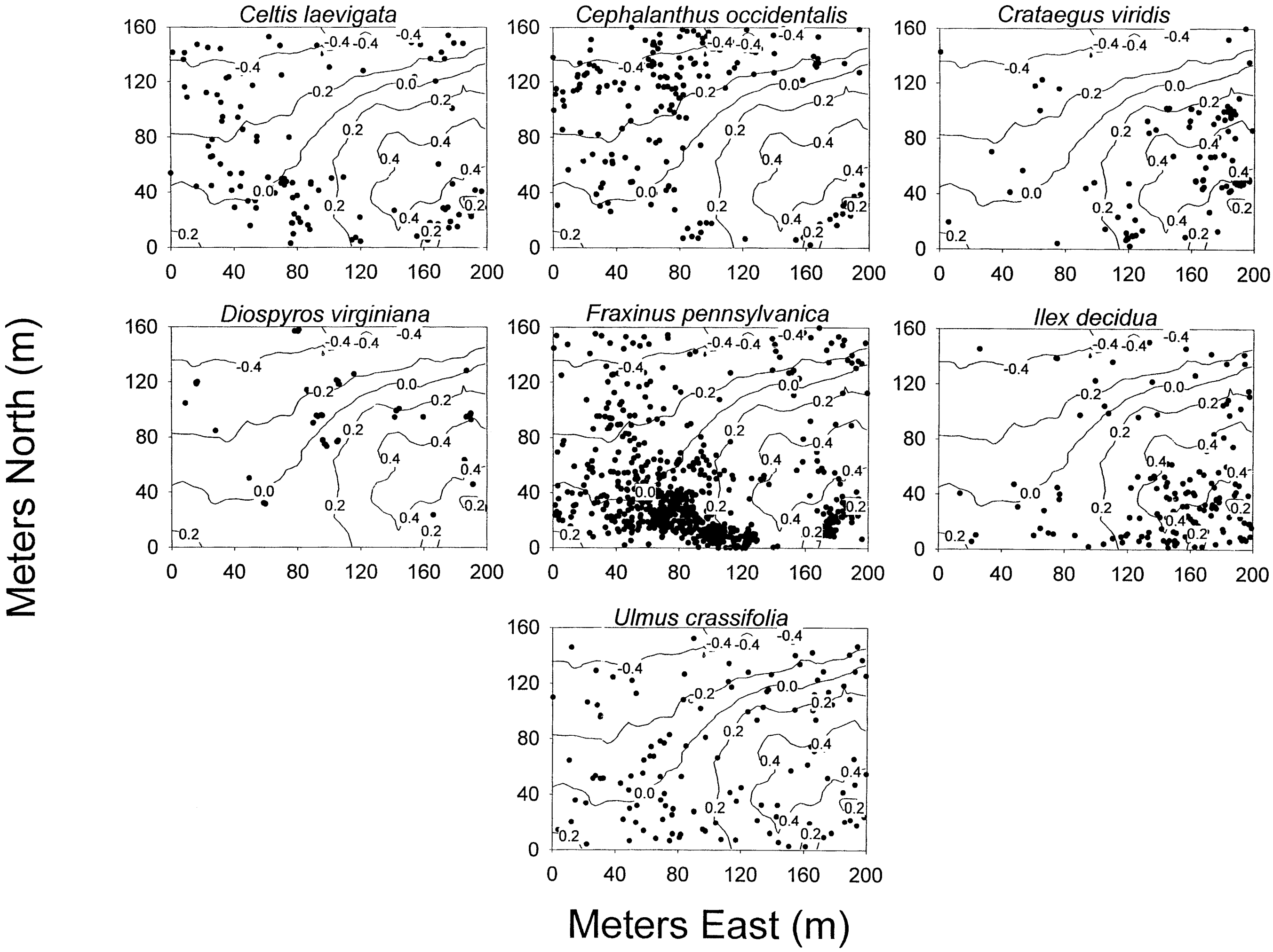

Figure 4. Maps of all individuals of six dominant tree species and *Cephalanthus occidentalis*.

fleshy fruits, occurred in the central portion of the field, usually in small clusters. *Ulmus crassifolia,* a light-seeded wind-dispersed species, was found throughout the field. The shrub *Cephalanthus occidentalis* was largely confined to areas lower than 0.2 m relative elevation.

The shrub *Baccharis halimifolia,* a wind-dispersed species in the *Asteraceae* (not included in Figure 4), was present in the seven highest elevation 100-m^2 plots of the 20 established in 1999. Across these plots, its percent cover averaged 22% and ranged from 2 to 75%. Patches of this species corresponded with sparser regions in the distributions of *F. pennsylvanica* and *C. laevigata* but overlapped with large portions of *C. viridis* and *I. decidua* distributions.

We have no data on natality, growth, mortality, or age structure of these populations, so inferences about the population dynamics based on height and diameter class distributions of individuals ≥1 m in height are based on several assumptions. First, we assume that age and size are closely related. Second, we assume that mortality of individuals ≥1 m in height is negligible and constant across size classes and years. Observations made during annual visits to the field suggest that this is a reasonable assumption. If these assumptions are accepted, then the main source of variation is in annual recruitment to the ≥1 m height class. The combination of variable germination, seedling survival, and growth among years is incorporated into this rate.

Size class distributions of *F. pennsylvanica, C. laevigata, D. virginiana,* and *C. viridis* (Figures 5 and 6) suggest that recruitment rates were initially low and have been increasing gradually. In these populations, most individuals are in the smaller size classes. Distributions of *I. decidua, U. crassifolia,* and *C. occidentalis* indicate initially low recruitment rates, a peak, and a return to lower levels. The largest tree in the field was an *Ulmus americana* with a height of 9.25 m and diameter of 21.1 cm at 30 cm above the ground. We do not know when this individual established.

The relationships of density and basal area per hect-

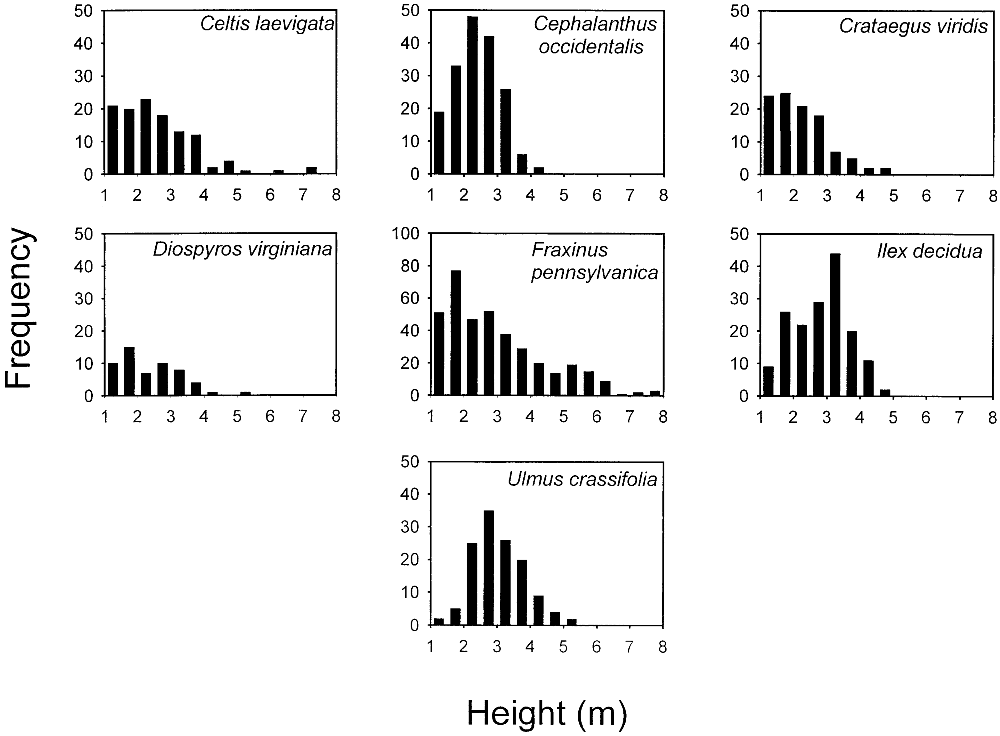

Figure 5. Height class distributions of six dominant tree species and *Cephalanthus occidentalis*.

are with relative elevation varied by species. Densities of *F. pennsylvanica*, *U. crassifolia*, and *U. americana* had symmetric, unimodal response curves along the gradient. Density of *C. occidentalis* increased monotonically toward lower elevations, while *C. viridis* and *I. decidua* showed monotonic increases in density toward higher elevations (Figure 7). *Fraxinus pennsylvanica*, *U. crassifolia*, and *U. americana* also displayed symmetric, unimodal responses for basal area, while *C. laevigata* required a skewed, unimodal curve. The basal area response of *I. decidua* was monotonic toward higher elevations (Figure 8). All of these response curves were statistically significant ($p < 0.05$), based on F-tests for change in deviance.

Celtis laevigata showed no significant trend in density in relation to elevation, mainly due to an unusually high value in the lowest elevation class. No significant trend in basal area was observed for *C. viridis*. The

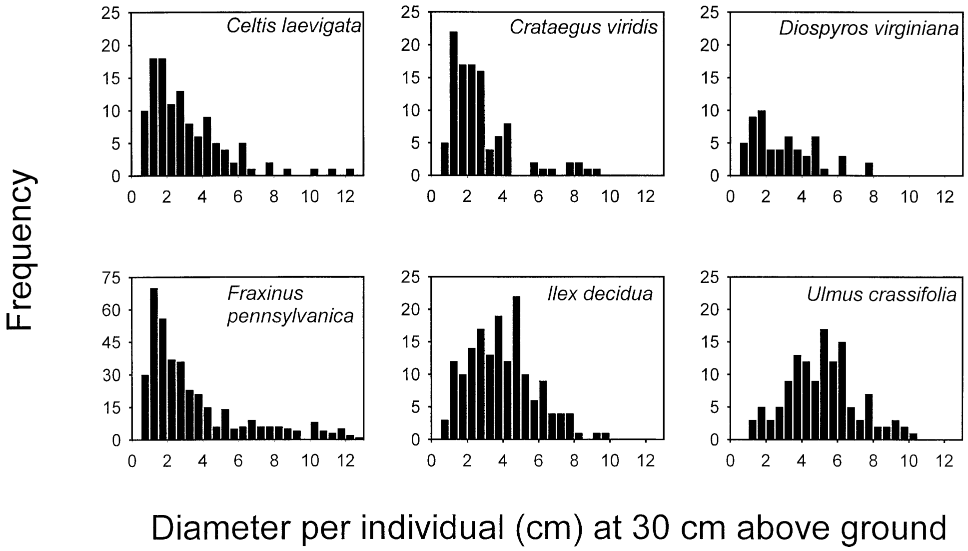

Figure 6. Diameter class distributions of six dominant tree species.

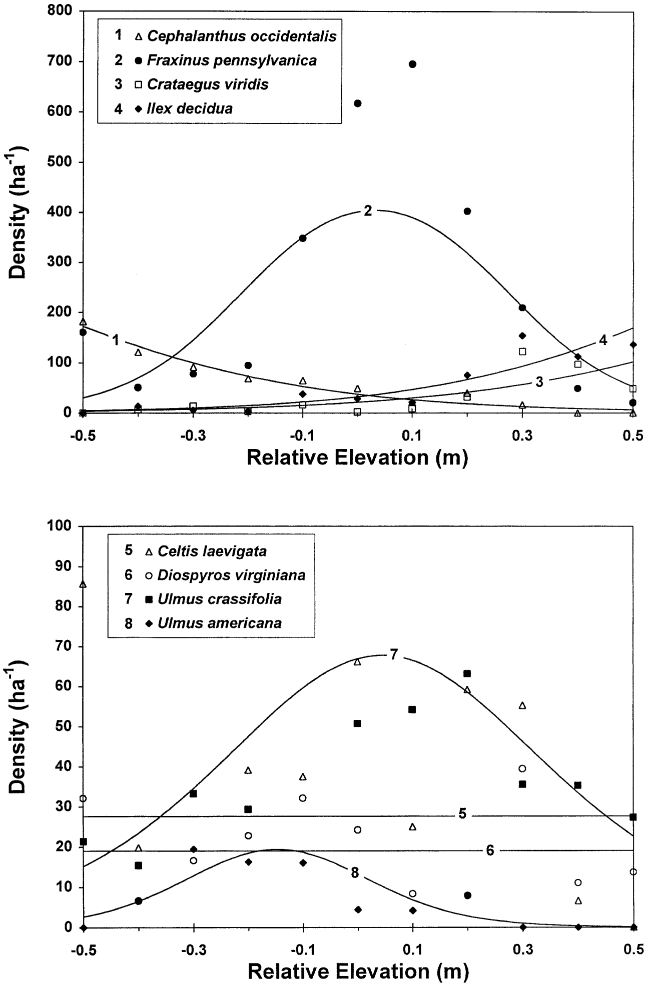

Figure 7. HOF models for density in relation to elevation. Except for *Celtis laevigata* and *Diospyros virginiana*, all models are significant ($p < 0.05$), based on F-tests for the change in deviance.

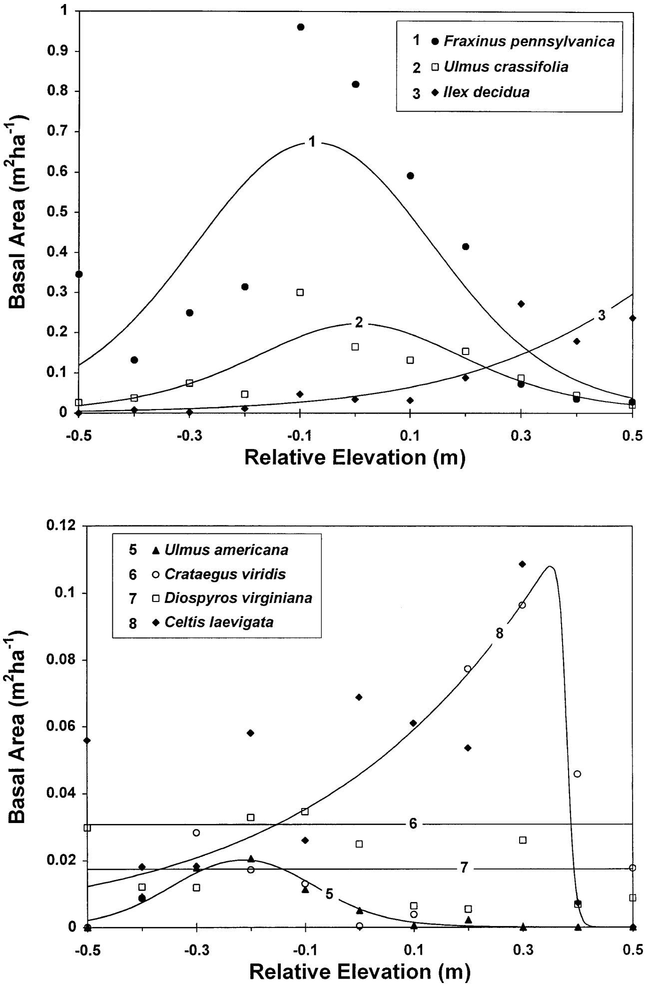

Figure 8. HOF models for basal area in relation to elevation. Except for *Crataegus viridis* and *Diospyros virginiana*, all models are significant ($p < 0.05$), based on F-tests for the change in deviance. The multi-stemmed shrub, *Cephalanthus occidentalis*, is omitted, since we did not measure its stem diameters.

data points suggest a bimodal response (Figure 8), which cannot be accommodated by HOF models. For *D. virginiana*, neither measure of abundance showed a significant trend with elevation.

The density of *F. pennsylvanica* also showed a clear relationship with distance from the southern edge of the site (Figure 9a), decreasing from a mean of about 800 ha^{-1} within 10 m of the southern edge to about 70 ha^{-1} at 80 m from the edge. This is consistent with wind dispersal from mature individuals on the southern levee system (Table 4). *Celtis laevigata* density decreased monotonically with distance from either edge of the field (Figure 9b), from a mean of about 45 ha^{-1} within 10 m of either edge to about 10 ha^{-1} at 80 m from the nearest edge. This species has small fleshy fruits that are dispersed by birds and mammals; mature individuals are present on both the southern and northern levee systems (Table 4).

DISCUSSION

Succession and the Hydrologic Gradient

Successional changes occurred in the ground layer vegetation over the 15-year period covered by the permanent quadrat data. This was evident from the strong correlation between time-since-abandonment and one of the two principal trends in species composition revealed by ordination. The time trend coincided with gradual shifts in dominance by annuals to herbaceous perennials during the first five years of succession (Battaglia et al. 1995), followed by loss of most annual species and increasing abundance of woody perennials over the subsequent ten years (1994–1999). The woody vine *Campsis radicans* was an exception to this pattern in that it was a dominant species throughout the 15-year period. By Year 16, a shrub and young

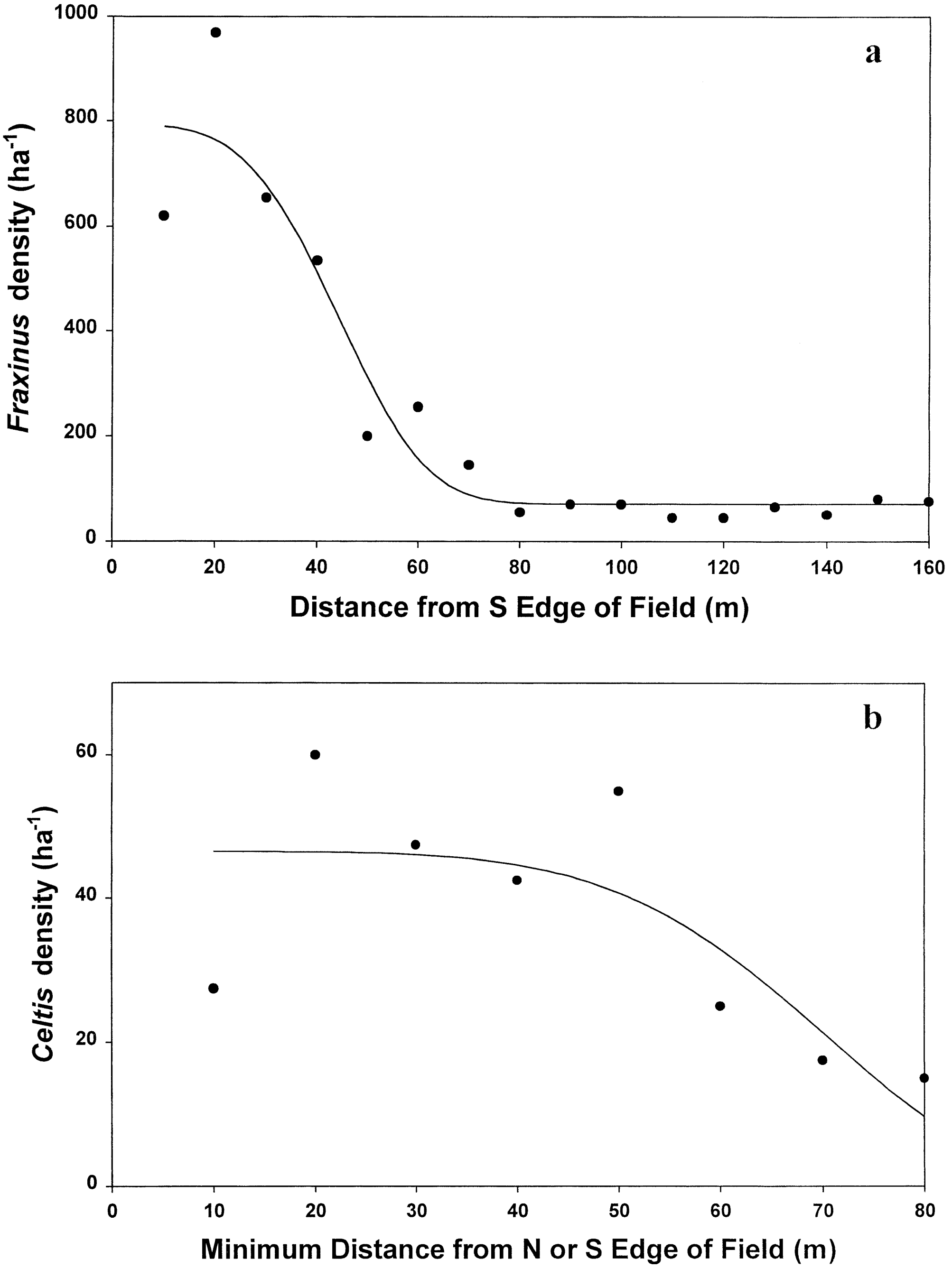

Figure 9. a) Exponential model for density of *Fraxinus pennsylvanica* in relation to distance from the southern edge of the site ($F_{4,12} = 45.5$, $p < 0.0001$). b) Exponential model for density of *Celtis laevigata* in relation to minimum distance from either the southern or northern edge of the site ($F_{3,5} = 22.7$, $p = 0.0024$).

tree layer had emerged from beneath the thick ground layer of vegetation. This recent shift indicates that a transition phase between old-field and young forest communities has begun (Bonck and Penfound 1945, Hopkins and Wilson 1974).

Compositional changes over time indicated an overall trend of directional succession, but the pattern was not uniform throughout the field. The second major compositional trend, approximately perpendicular to that of time-since-abandonment, was significantly correlated with elevation, although the identity of species present and beta diversity along the elevation gradient varied among years. It is likely that annual variation in precipitation and local flooding from Bayou Lafourche (Battaglia et al. 1995), as well as increasing establishment and survival of perennial species through time, contributed to inter-annual differences in the pattern along the elevation gradient. The most pronounced shift in our study occurred in 1986, the year with the lowest cumulative rainfall in the pre-growing season (November–April). Beta diversity was lowest along the gradient and corresponded to species typical of higher elevations in wetter years colonizing lower sites. Ours is not the first study to report annual variation in compositional trends along environmental gradients in old-field communities. For example, in a classic study of old-field succession in the North Carolina Piedmont, Keever (1950) described an early successional field with a slight slope (*i.e.*, moisture gradient) in which *Aster* spp. dominated in one year but was replaced by broomsedge (*Andropogon virginicus*) in the following year. This replacement occurred throughout the field, except in the lower, wetter corner. In contrast to our results, convergence did occur in her study site, as *Aster* spp. was eventually replaced by *A. virginicus*, even in the wetter corner.

Our study illustrates that variation in species composition along the elevation gradient persists as succession proceeds, in accordance with the climax pattern concept of Whittaker (1967). Lower and higher elevation plots were moving in the same general direction in the ordination, and there did not appear to be a long- term trend toward divergence or convergence between the two groups. Further, based on the significant responses of most species in the emerging tree layer to elevation, there is no indication that convergence will occur in the developing forest community. This pattern is consistent with those found in mature bottomland hardwood forests where small changes in elevation and flooding frequency parallel shifts in community composition (Wharton et al. 1982, Huenneke and Sharitz 1986, Titus 1990, Sharitz and Mitsch 1993, Jones et al. 1994, Allen and Sharitz 1999, Battaglia et al. 1999).

The influence of microtopography on successional patterns has not been emphasized in studies of bottomland old fields (Bonck and Penfound 1945, Hopkins and Wilson 1974, Allen 1997, but see Battaglia et al. 1995). We believe that it is important to take into account the hydrologic gradient associated with microtopography. Allen et al. (1998) report higher seedling densities in undisked versus disked fields and attribute this, in part, to the remaining elevated planting surfaces in undisked fields that provide safe sites for seedling establishment. Retention, restoration, or enhancement of microtopographic variation may be key to restoring a template that can support diverse assemblages of floodplain species.

Invasion Patterns of Woody Species and Emergence of a Young Tree Layer

Early forest development and composition were influenced primarily by the local seed source and elevation (hydrology) in the study site. Invasion by woody species soon after abandonment has been documented in other bottomlands (Bonck and Penfound 1945, Hopkins and Wilson 1974, Clewell 1981, Allen 1997). Indeed, 13 of the 16 woody tree and shrub species found in 2000 in our study were recorded in the first five years of succession during floristic surveys throughout the study site (Battaglia 1991). We have no data on the distribution and demography of small seedlings below the thick ground layer of old-field vegetation, so we can only speculate about their turnover and survival. We began to observe seedlings overtopping the ground layer in 1994. By 2000, tree seedlings and saplings were very abundant and conspicuous, and the field was in a transitional stage between old-field and young forest. This stage is characterized by a rich mixture of old-field vegetation, including forbs, grasses, vines, and shrub and tree species that have emerged to varying degrees above the ground layer. Eleven of the latter species are capable of becoming canopy trees. Eleven of the 16 species of trees and shrubs had potential local seed sources on one or both of the levee systems that parallel the southern and northern edges of the study site, underscoring the influence of nearby forest fragments on species composition.

The current distribution of species is a manifestation of past dispersal events and establishment conditions. In secondary vegetation, both time-since-abandonment and environmental gradients can influence community composition (Pascarella et al. 2000). Assuming that size and age are closely related, size-class distributions indicate that recruitment rates to the $\geq$1 m height class of the seven dominant species in this study were low initially and then gradually improved. It appears that the recruitment window is still open and that populations of *F. pennsylvanica*, *C. laevigata*, *D. virginiana*, and *C. viridis* are still increasing. In contrast, distributions of *I. decidua*, *U. crassifolia*, and *C. occidentalis* suggest that recruitment levels peaked and then decreased substantially. We suspect that this pattern reflects episodic recruitment in *U. crassifolia* and a decreasing population of the shrub *C. occidentalis*. The majority of the larger individuals of *C. occidentalis* have high vine cover and stem mortality (unpublished data). Recruitment of *I. decidua* may have decreased, but the population is not in danger of senescing, as many of the stems in the field are now reproductively mature. Size-class distributions and relative abundance of species are expected to shift as succession continues and canopy closure occurs.

It is unknown whether propagule deficiency, unfavorable environmental conditions in the recently abandoned field, or a combination of the two contributed to low levels of seedling recruitment early in succession. Many of the trees along the levees have become reproductively mature during the course of the study, so influx of seeds has likely increased with time. Also, cover of herbaceous species and development of the shrub layer in recent years may have facilitated establishment of some tree species. Distribution of the shrub, *Baccharis halimifolia*, which is largely confined to higher elevations, overlaps widely with those of *C. viridis* and *I. decidua,* two species primarily dispersed by birds. Clumping of bird-dispersed species in association with shrubs has been reported in other old fields (Foster and Gross 1999), and there are several possible reasons why shrubs may be recruitment foci for tree species at our site. First, dispersal may be greater in shrub patches because birds use them as perches (Holl et al. 2000), and they provide a haven for dispersers from their predators (Jordano and Schupp 2000). Second, seedling densities may be greater due to lower seed predation and improved microsite suitability for germination and seedling establishment (Callaway 1992). Finally, mature shrubs may reduce the cover of herbaceous species that would otherwise compete with tree seedlings (Posada et al. 2000).

While shrubs may influence pattern and rate of tree establishment (Callaway 1992), the effects of shrubs are not necessarily constant and positive due to changes in shrub cover through time. It is possible that previously sparse cover of *B. halimifolia* was suitable for *I. decidua* establishment and seedling growth, but increasingly dense shrub cover may be limiting further recruitment in those patches. Shrubs may also have different effects among tree species (Callaway 1992), and mortality under shrubs may vary (Kollmann and Grubb 1999). Spatial distributions of *F. pennsylvanica*, *C. occidentalis*, and C. *laevigata* were negatively associated with areas of high *B. halimifolia* cover, yet they have invaded elsewhere in the old field.

As in many studies of bottomland forests, abundance patterns of most of the dominant species were significantly related to the elevation (hydrology) gradient (Titus 1990, Sharitz and Mitsch 1993, Jones et al. 1994). Without experiments, however, it is impossible to isolate effects of biotic from abiotic filters. Since *B. halimifolia* is confined to the higher elevations, we cannot determine whether *C. viridis* and *I. decidua* are most abundant in the eastern portion of the field and *C. occidentalis* is absent there due to suitability of environmental conditions, presence of *B. halimifolia*, or both. Nevertheless, the hydrologic gradient is underlying these patterns and may influence intensity of biotic interactions (Budelsky and Galatowitsch 2000). Elevation does not account for the spatial distribution of *Diospyros virginiana*, a species with large fleshy fruits. This species had a low overall abundance and was found at a wide range of elevations at the maximum distance from seed source (the middle of the field), indicating that it can be dispersed great distances and may not be particularly sensitive to the gradient.

Species richness in the emerging tree layer corresponds with values reported for other abandoned bottomland sites with nearby seed sources (Allen 1997), and they are approaching those reported for mature forests in the area (Huffman 1980, Devall 1990). It remains unclear, however, whether composition of mature communities that have developed through natural invasion of abandoned fields will closely resemble that of old-growth forests.

The extent to which individual species present in nearby forest patches are represented in the overall composition of the target site depends on proximity to the seed source, which can influence rate of seedling establishment, abundance, and spatial distribution of individual species (Golley et al. 1994, Pinder et al. 1995, Brunet et al. 2000). Distance to seed source seems to be an important filter on establishment of *F. pennsylvanica and C. laevigata,* but we cannot conclusively separate effects of this factor from those discussed above. Both species were low in density in the center of the site, a pattern typical of larger fields (Pinder et al. 1995). Sharply decreasing densities of these species suggest some dispersal limitation between 60 and 80 m from the edge of the field, a threshold similar to that reported by Allen (1997). It is probable that species have different dispersal limitation thresholds and that the thresholds become less critical with time since abandonment (Allen 1997, Brunet et al. 2000). *Quercus* spp. are scarce or absent in our study site although abundant on the adjacent levees. This may be due to the initial low abundance of the necessary animal dispersers. In addition, seed predation may limit the establishment of large-seeded species such as *Quercus* spp. and *Carya* spp. (DeSteven 1991).

The combination of factors leading to successful reforestation in this study does not occur everywhere. The potential for natural reestablishment in abandoned bottomlands must be assessed on a case-by-case basis. If the distance to nearest seed source exceeds 60–80 m, natural invasion of some woody species may be delayed indefinitely (Allen 1997, Allen et al. 1998). Supplemental plantings may then be necessary to improve similarity to reference sites (Aide et al. 2000, Pascarella et al. 2000). The composition of propagule sources must also be evaluated carefully. If they are depauperate in species or if they lack desirable species, intervention by managers may be warranted, possibly including seeding or planting. Finally, the source species must be well-matched to the target site conditions, particularly in terms of flood tolerance (Stanturf et al.

2000), which requires some information about the hydrologic range and variation within the site.

Restoring ecosystem connectivity and functioning in this highly disturbed system will require scaling up from individual sites and building a network of abandoned old fields linked with forest fragments. Organizations such as the Louisiana Department of Wildlife and Fisheries and The Nature Conservancy of Louisiana have already begun building these linkages; however, the legacy of extensive and intensive hydrologic modification and agricultural use in the LMAV landscape presents a formidable challenge. Ultimately, the degree to which separate sites are restored and interconnected will be determined by land managers balancing local management goals, costs, and feasibility of restoration in a highly disturbed and increasingly urbanized setting. Successfully restoring, reforesting, and reconnecting portions of the great floodplain of the Mississippi River in the LMAV will require a refined and improved understanding of succession and reestablishment of bottomland hardwood forest in agricultural fields that are dominant features in the current landscape.

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LITERATURE CITED

Aide, T. M., J. K. Zimmerman, J. B. Pascarella, L. Rivera, and J. Marcano-Vega. 2000. Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. Restoration Ecology 8:328–338.

Allen, B. P. and R. R. Sharitz. 1999. Post-hurricane vegetation dynamics in old-growth forests of the Congaree Swamp National Monument. p. 306–312. *In* On the Frontiers of Conservation. George Wright Society Bulletin, Hancock, MI, USA.

Allen, J. A. 1990. Establishment of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. Southern Journal of Applied Forestry 14:206–210.

Allen, J. A. 1997. Reforestation of bottomland hardwoods and the issue of woody species diversity. Restoration Ecology 5:125–134.

Allen, J. A., J. McCoy, and B. D. Keeland. 1998. Natural establishment of woody species on abandoned agricultural fields in the lower Mississippi Valley: first- and second-year results. p. 263–268. *In* T. A. Waldrop (ed.) Proceedings of the ninth biennial southern silvicultural research conference. USDA Forest Service, Southern Research Station, Asheville, NC, USA.

Austin, M. P. and M. J. Gaywood. 1994. Current problems of environmental gradients and species response curves in relation to continuum theory. Journal of Vegetation Science 5:473–482.

Battaglia, L. L. 1991. Early secondary succession in a bottomland hardwood area. M. S. Thesis. University of Louisiana, Monroe, LA, USA.

Battaglia, L. L., J. R. Keough, and D. W. Pritchett. 1995. Early secondary succession in a southeastern U. S. alluvial floodplain. Journal of Vegetation Science 6:769–776.

Battaglia, L. L., R. R. Sharitz, and P. R. Minchin. 1999. Patterns of seedling and overstory composition along a gradient of hurricane disturbance in an old-growth bottomland hardwood community. Canadian Journal of Forest Research 29:144–156.

Bonck, J. and W. T. Penfound. 1945. Plant succession on abandoned farmland in the vicinity of New Orleans, Louisiana. American Midland Naturalist 33:520–529.

Bray, J. R. and J. T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27: 325–349.

Brunet, J., G. von Oheimb, and M. Diekmann. 2000. Factors influencing vegetation gradients across ancient- recent woodland borderlines in southern Sweden. Journal of Vegetation Science 11: 515–524.

Budelsky, R. A. and S. M. Galatowitsch. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37:971–985.

Callaway, R. M. 1992. Effects of shrubs on recruitment of *Quercus douglasii* and *Quercus lobata* in California. Ecology 73:2118–2128.

Clewell, A. F. 1981. Vegetational restoration techniques on reclaimed phosphate strip m mines in Florida. Wetlands 1:158–170.

Creasman, L., N. J. Craig, and M. Swan. 1992. The forested wetlands of the Mississippi River: an ecosystem in crisis. The Nature Conservancy, Baton Rouge, LA, USA.

Dahl, T. E. 1990. Wetlands losses in the United States 1780s to 1980s. U. S. Dept. of the Interior, Fish and Wildlife Service, Washington, DC, USA.

Dahl, T. E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1987. U. S. Dept. of the Interior, Fish and Wildlife Service, Washington, DC, USA.

Dahl, T. E. and C. E. Johnson. 1991. Status and trends of wetlands in the conterminous United States, mid-1970's to mid-1980's. U. S. Dept. of the Interior, Fish and Wildlife Service, Washington, DC, USA.

Dargie, T. C. D. 1984. On the integrated interpretation of indirect site ordinations: a case study using semi-arid vegetation in southeastern Spain. Vegetatio 55:37–55.

DePoe, C. E. and D. W. Pritchett. 1986. Secondary succession in a cleared bottomland hardwood area. Proceedings of the Louisiana Academy of Science 49:23–33.

DeSteven, D. 1991. Experiments on mechanisms of tree establishment in old-field succession—seedling emergence. Ecology 72: 1066–1075.

DeSteven, D. and R. R. Sharitz. 1997. Differential recovery of a deepwater swamp forest across a gradient of disturbance intensity. Wetlands 17:476–484.

Devall, M. S. 1990. Cat Island Swamp: window to a fading Louisiana ecology. Forest Ecology and Management 33/34:303–314.

Faith, D. P. and R. H. Norris. 1989. Correlation of environmental variables with patterns of distribution and abundance of common and rare freshwater macroinvertebrates. Biological Conservation 50:77–98.

Faith, D. P., P. R. Minchin, and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio 69:57–68.

Foster, B. L. and K. L. Gross. 1999. Temporal and spatial patterns of woody plant establishment in Michigan old fields. American Midland Naturalist 142:229–243.

Golley, F. B., J. E. Pinder, P. J. Smallidge, and N. J. Lambert. 1994. Limited invasion and reproduction of loblolly pines in a large South-Carolina old field. Oikos 69:21–27.

Hefner, J. M. and J. D. Brown. 1985. Wetland trends in the southeastern United States. Wetlands 4:1–11.

Hefner, J. M., B. O. Wilen, T. E. Dahl, and W. E. Frayer. 1994. Southeast wetlands: status and trends, mid- 1970's to mid-1980's. U. S. Dept. of the Interior, Fish and Wildlife Service, Southeast Region, Atlanta, GA, USA and United States Environmental Protection Agency, Region IV, Atlanta, GA, USA.

Holl, K. D., M. E. Loik, E. H. V. Lin, and I. A. Samuels. 2000.

Tropical montane forest restoration in Costa Rica: overcoming barriers to dispersal and establishment. Restoration Ecology 8: 339–349.

Hopkins, W. E. and R. E. Wilson. 1974. Early oldfield succession on bottomlands of southeastern Indiana. Castanea 39:57–71.

Huenneke, L. F. and R. R. Sharitz. 1986. Microsite abundance and distribution of woody seedlings in a South Carolina cypress-tupelo swamp. American Midland Naturalist 115:328–335.

Huffman, R. T. 1980. The relation of flood timing and duration to variation in selected bottomland hardwood communities of southern Arkansas. U. S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, USA. Miscellaneous paper EL-80-4.

Huisman, J., H. Olff, and L. F. M. Fresco. 1993. A hierarchical set of models for species response analysis. Journal of Vegetation Science 4:37–46.

Jones, R. H. and R. R. Sharitz. 1998. Survival and growth of woody plant seedlings in the understorey of floodplain forests in South Carolina. Journal of Ecology 86:574–587.

Jones, R. H., R. R. Sharitz, P. M. Dixon, D. S. Segal, and R. L. Schneider. 1994. Woody plant regeneration in four floodplain forests. Ecological Monographs 64:345–367.

Jordano, P. and E. W. Schupp. 2000. Seed disperser effectiveness: the quantity component and patterns of seed rain for *Prunus mahaleb*. Ecological Monographs 70:591–615.

Kantvilas, G. and P. R. Minchin. 1989. An analysis of epiphytic lichen communities in Tasmanian cool temperate rainforest. Vegetatio 84:99–112.

Kellison, R. C., M. J. Young, R. R. Braham, and E. J. Jones. 1998. Major alluvial floodplains. p. 291–323. *In* J. G. Messina and W. H. Conner (eds.) Southern Forested Wetlands Ecology and Management. Lewis Publishers, New York, NY, USA.

Keever, C. 1950. Causes of succession on old fields of the Piedmont, North Carolina. Ecological Monographs 20:229–250.

King, S. L. and B. D. Keeland. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology 7:348–359.

Kollmann, J. and P. J. Grubb. 1999. Recruitment of fleshy-fruited species under different shrub species: control by under-canopy environment. Ecological Research 14:9–21.

MacDonald, P. O., W. E. Frayer, and J. K. Clauser. 1979. Documentation, chronology, and future projections of bottomland hardwood habitat loss in the Lower Mississippi Alluvial Plain. Vols. 1 and 2. U. S. Fish and Wildlife Service, Vicksburg, MS, USA.

McKnight, J. S., D. D. Hook, O. G. Langdon, and R. L. Johnson. 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. p. 29–69. *In* J. R. Clark and J. Benforado (eds.) Wetlands of Bottomland Hardwood Forests. Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

Minchin, P. R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69:89–107.

Minchin, P. R. 1989. DECODA user's manual. Research School of Pacific Studies. Australian National University, Canberra, Australia.

Newling, C. J. 1990. Restoration of bottomland hardwood forests in the lower Mississippi Valley. Restoration and Management Notes 8:23–28.

National Oceanic and Atmospheric Administration. 2001. Daily precipitation data for Monroe NLU, station 166314, 1985 to 1999. National Climatic Data Center, Asheville, NC, USA. http://www.ncdc.noaa.gov/ (16 March, 2001).

Oksanen, J. 1996. HOF: Gradient analysis using Huisman-Olff-Fresco models with maximum likelihood software for HOF models. http://cc.oulu.fi/~jarioksa/pages/hof2.htm (1 March, 2001).

Oksanen, J. 1997. Why the beta-function cannot be used to estimate skewness of species responses. Journal of Vegetation Science 8: 147–152.

Pascarella, J. B., T. M. Aide, M. I. Serrano, and J. K. Zimmerman. 2000. Land-use history and forest regeneration in the Cayey Mountains, Puerto Rico. Ecosystems 3:217–228.

Pinder, J. E., F. B. Golley, and R. F. Lide. 1995. Factors affecting limited reproduction by loblolly pine in a large old field. Bulletin of the Torrey Botanical Club 122:306–311.

Posada, J. M., T. M. Aide, and J. Cavelier. 2000. Cattle and weedy shrubs as restoration tools of tropical montane rainforest. Restoration Ecology 8:370–379.

Radford, A. E., H. E. Ahles, and C. R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press, Chapel Hill, NC, USA.

Robertson, P. A., G. T. Weaver, and J. A. Cavanaugh. 1978. Vegetation and tree species patterns near the northern terminus of the southern floodplain forest. Ecological Monographs 48:249–267.

Sandercock, G. 1997. Evaluating Data Standardisation in Vegetation Analysis Using Simulated Data. Honours Thesis. The University of Melbourne, Melbourne, Australia.

SAS Institute Inc. 1989. SAS/STAT User's Guide, Version 6, 4th edition, volume 2. SAS Institute Inc., Cary, NC, USA.

SPSS Inc. 1997. SigmaPlot 4.0 User's Manual. SPSS Inc., Chicago, IL, USA.

Sharitz, R. R. 1992. Bottomland hardwood wetland restoration in the Mississippi Drainage. p. 455–463. *In* National Research Council (eds.) Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press, Washington, DC, USA.

Sharitz, R. R. and W. J. Mitsch. 1993. Southern floodplain forests. p. 311–371. *In* W. H. Martin, S. G. Boyce, and A. C. Echternacht (eds.) Biodiversity of the Southeast United States/Lowland Terrestrial Communities. Wiley and Sons, Inc., New York, NY, USA.

Stanturf, J. A., E. S. Gardiner, P. B. Hamel, M. S. Devall, T. D. Leininger, and M. E. Warren Jr. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry 98:10–16.

Titus, J. H. 1990. Microtopography and woody plant regeneration in a hardwood floodplain swamp in Florida. Bulletin of the Torrey Botanical Club 117:429–437.

Turner, R. E., S. W. Forsythe, and N. J. Craig. 1981. Bottomland hardwood forest land resources of the southeastern United States. p. 13–28. *In* J. R. Clark and J. Benforado (eds.) Wetlands of Bottomland Hardwood Forests. Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

United States Department of Agriculture. 2001. The PLANTS Database, Version 3.1. National Plant Data Center, Baton Rouge, LA, USA. http://plants.usda.gov/ (1 April, 2001).

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, and T. W. Sipe. 1982. The ecology of bottomland hardwood swamps of the Southeast: a community profile. U. S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, USA. FWS/OBS 81/37.

Whittaker, R. H. 1967. Gradient analysis of vegetation. Biological Reviews 49:207–264.

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Great Trinity Forest Management Plan

HARDWOOD SILVICULTURE

A Guide to Bottomland Hardwood Restoration

(USGS BRD Information and Technology Report 2000-0011, USDA Forest Service General Technical Report SRS - 40)

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A Guide to Bottomland Hardwood Restoration

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Preface

The primary focus of this guide is to provide information for land managers and landowners who want to reestablish bottomland hardwood forest vegetation, particularly the trees, on lands where they formerly occurred. Restoration and reforestation are approached with the realization that hydrology, as the driving force of wetland ecosystems, must be explicitly considered in all projects. Without the proper hydrologic regime for the site conditions and tree species selected for planting, it is unlikely that a project will be a success. It is assumed that the goal of the audience using this guide is at least the reestablishment of bottomland hardwood forest systems and hopefully the restoration of all functions and values associated with these forests (e.g., storage of floodwaters, water quality improvement, provision of wildlife habitat, etc.).

It is unlikely that a publication will ever be produced that contains all the information needed for an untrained person to plan and implement a completely successful restoration project. Certainly, this guide has no such pretensions. We have tried to make the guide as comprehensive as possible but concise, realizing there is probably much that we have missed. In addition, there are currently information needs expressed by practitioners that have not been adequately addressed by researchers.

This guide will provide the reader with a reasonably comprehensive introduction to the wide range of activities and techniques which, taken together, make up the process of bottomland hardwood restoration as it is now understood. Hopefully, this guide will also provide valuable information to experienced, professional ecosystem ecologists, especially those who have worked mainly with other types of wetland systems.

Whenever possible, the novice restorationist should seek opportunities to work with experienced professionals during every phase of their projects, from initial planning, through implementation, to monitoring and reporting. Opportunities to visit ongoing or completed restoration projects should also be sought.

First and foremost, though, understanding the ecology of bottomland hardwood systems is vitally important. Without a fundamental understanding of factors such as the seasonal patterns of flooding and groundwater dynamics, species-site relationships, seed dispersal mechanisms, plant establishment requirements, and plant-animal interactions, a restoration project is unlikely to be fully successful. In many ways, ongoing efforts to reestablish bottomland forest systems is a continuing experiment. As new information is gained, it should be cycled back into the decision-making process and subsequent forest reestablishment efforts.

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A Guide to Bottomland Hardwood Restoration

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Abstract: During the last century, a large amount of the original bottomland hardwood forest area in the United States has been lost, with losses greatest in the Lower Mississippi Alluvial Valley and East Texas. With a holistic approach in mind, this manual describes methods to restore bottomland hardwoods in the lower Midwest, including the Lower Mississippi Alluvial Valley and the southeastern United States. Bottomland hardwoods in this guide include not only the hardwood species that predominate in most forested floodplains of the area but also the softwood species such as baldcypress that often co-occur. General restoration planning considerations are discussed as well as more specific elements of bottomland hardwood restoration such as species selection, site preparation, direct seeding, planting of seedlings, and alternative options for revegetation. We recognize that most projects will probably fall more within the realm of reforestation or afforestation rather than a restoration, as some site preparation and the planting of seeds or trees may be the only actions taken. Practical information needed to restore an area is provided in the guide, and it is left up to the restorationist to decide how complete the restoration will be. Postplanting and monitoring considerations are also addressed. Restoration and management of existing forests are included because of the extensive areas of degraded natural forests in need of rehabilitation.

Key words: bottomland hardwood forest, forested wetlands, Lower Mississippi Alluvial Valley, restoration, silviculture

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Chapter 1: Introduction

Definition of Bottomland Hardwoods

The term "bottomland hardwoods" is generally used to describe both the dominant forest tree species and the major forest types that occur on floodplains in the lower Midwest and the southeastern United States. Occasionally, the term is also applied to floodplain forests in other regions. Bottomland hardwoods in much of the scientific literature, and in this guide, include not only the hardwood species that predominate in most forested floodplains but also the softwood species such as baldcypress. The Society of American Foresters' forest cover type classification system (Eyre, 1980) identifies 16 forest cover types found in the southern and central United States (see Appendix A for descriptions) that are considered bottomland hardwoods (table 1.1).

In this guide, bottomland hardwoods are treated as wetlands. Under the wetlands classification system used by the U.S. Fish and Wildlife Service (Cowardin and others, 1979), bottomland hardwoods are in the palustrine system, forested wetland class, and primarily either in the broad-leaved deciduous or needle-leaved deciduous subclasses. It is recognized, however, that not all bottomland hardwoods may be classified as jurisdictional wetlands under the jurisdiction of section 404 of the Clean Water Act (U.S. Army Corps of Engineers, 1987), as there are several methodologies for identifying wetlands. Regardless of whether or not a particular project involves jurisdictional wetlands, the basic principles described in this text will remain the same.

Table 1.1. Bottomland hardwood forest cover types.[1]

Type	SAF Number[1]
River birch-Sycamore	61
Silver maple-American elm	62
Cottonwood	63
Pin oak-Sweetgum	65
Willow oak-Water oak-Laurel (diamondleaf) oak	88
Live oak	89
Swamp chestnut oak-Cherrybark oak	91
Sweetgum-Willow oak	92
Sugarberry-American elm-Green ash	93
Sycamore-Sweetgum-American elm	94
Black willow	95
Overcup oak-Water hickory	96
Baldcypress	101
Baldcypress-Tupelo	102
Water tupelo-Swamp tupelo	103
Sweetbay-Swamp tupelo-Redbay	104

[1] Numbers refer to the classification system used by the Society of American Foresters (SAF). See Eyre (1980) and Appendix A for cover type descriptions.

The common and scientific names, along with information on habitat, flood and shade tolerance, seed ripening and storage requirements, and reproductive characteristics of many tree species common to southern bottomland hardwood forests are given in Chapter 4. Table 13.2 contains the common and scientific names of some wildlife species common in bottomland hardwood forests. In addition, Appendix B lists the common and scientific names of all species mentioned in the text.

Geographic Scope

This guide is designed primarily to provide information for restoration efforts in the lower Midwest, including the Lower Mississippi Alluvial Valley (LMAV; extending from the southern tip of Illinois to the Gulf of Mexico and including portions of Illinois, Missouri, Kentucky, Tennessee, Arkansas, Mississippi, and Louisiana) and the southeastern United States (fig. 1.1). The area with perhaps the greatest forested wetland losses and potential for restoration is the delta portion of Arkansas, Louisiana, and Mississippi. To a lesser degree, the methods described here will be applicable to forested wetlands throughout the United States.

What is Restoration?

Throughout this guide, "restoration" refers to the ultimate goal of bottomland hardwood reestablishment projects. It is therefore necessary to discuss the concept of restoration and contrast it with other commonly used terms, such as "reforestation," "reclamation," "creation," and "enhancement."

Ecological restoration is defined as the return of an ecosystem to a close approximation of its condition prior to disturbance (National Research Council, 1992). This definition, supported by the Society for Ecological Restoration, stresses that restoration is intentional and that it emulates the structure, function, diversity, and dynamics of a previously existing natural ecosystem. The Natural Resources Conservation Service (NRCS) defines a restored wetland as "a rehabilitated degraded wetland where the soils, hydrology, vegetative community, and biological habitat are returned to the original condition to the extent practicable" (NRCS, 1998). The NRCS's definition recognizes that it may not always be possible to completely restore a site to some previous condition, but that it is still desirable to restore it to the greatest extent possible.

These definitions of restoration serve to highlight some of the difficult issues facing restorationists. Although the definitions are seemingly straightforward, questions about what constitutes predisturbance or original forest conditions are ambiguous and need to be considered because they are often open to debate within

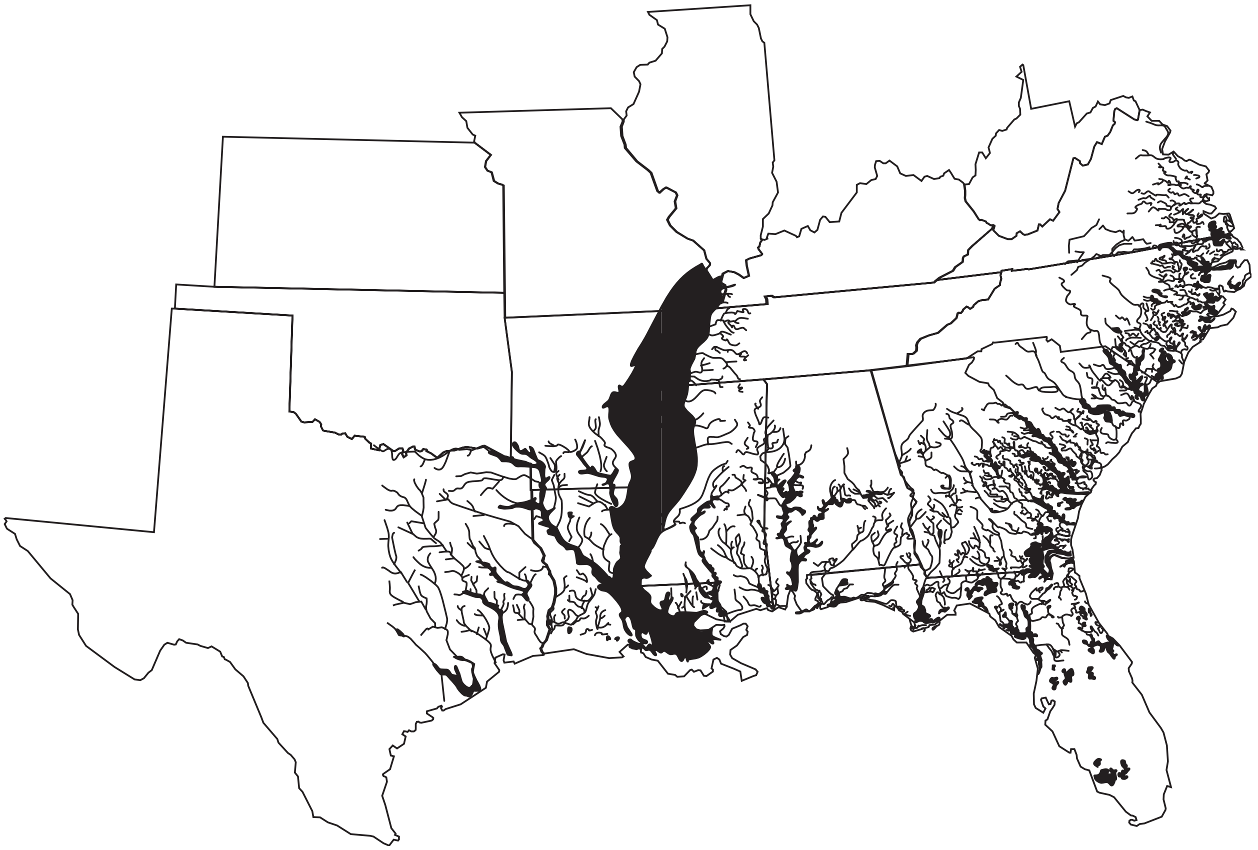

Figure 1.1. Distribution of bottomland hardwood forests along rivers and streams in the lower Midwest and southeastern United States. The dark band shows the extensive area covered by this forest type along the lower Mississippi River (modified from Putnam and others, 1960).

the scientific community. During the height of Pleistocene glacial activity, the forests of the southeastern United States included many boreal forest species such as spruce and fir (Delcourt and Delcourt, 1987). While it may be obvious that we should not try to restore to the Pleistocene community type, it is often not so obvious that forests have been naturally changing for eons and will continue to do so. Factors that have shaped the structure, function, diversity, and dynamics of bottomland hardwood forests over the last 500 years (less than the lifespan of some individual trees in the region) include natural disturbances (e.g., hurricanes, droughts, lightning-caused fires), Native Americans' agricultural practices and use of fire, and the agricultural, silvicultural, drainage, and flood control practices of European settlers. Restorationists need to be aware that, in a sense, they are trying to hit a moving target. Trying to restore to a previously existing natural ecosystem is less important than matching the tree species to be planted with the topographic, soil, and hydrologic conditions that will exist on the site after the project is completed. We must, therefore, use best judgement and any available data to determine the composition and structure of the forests we want to restore.

True ecological restoration may not be possible in many cases because of factors beyond the restorationist's control. For example, Schneider and others (1989) have shown that practically every major stream and hundreds of smaller ones throughout the southeastern United States have been affected by major construction projects. Such projects often affect the timing, magnitude, and duration of flooding as well as groundwater dynamics (i.e., a site's hydrology). Ideally, restorationists would be able to restore the hydrologic regime of their restoration sites, but it is rarely possible to reverse the impacts of major construction projects that affect hundreds or thousands of square kilometers of land. Because hydrology drives wetland ecosystems and determines the type of wetland that will develop, it must be restored if possible. If complete hydrologic restoration cannot be accomplished, then the trees to be planted must be selected based on the expected hydrologic regime. If only the hydrology is restored (a partial restoration), the vegetation and soils will develop naturally over a period of many years (and eventually become a full restoration).

The lack of ability to conduct a full restoration does not eliminate the importance of restoring those functions and values that we understand or restoring an area as close as possible to its previous condition. Restorationists, then, may frequently have to settle for more modest goals than complete ecological restoration, such as partial restoration or one of the terms described below: reclamation, reforestation, creation, or enhancement. Regardless of the level of restoration, the restorationist should maintain a holistic approach to each project and, to the greatest extent possible, establish an ecological community that is not only as close as possible to the original forest but is also well matched to the environmental conditions that will exist on the completed site.

Reclamation is defined by Jordan and others (1988, p. 55) as "any deliberate attempt to return a damaged ecosystem to some kind of productive use or socially acceptable condition short of restoration." Reforestation is defined by the Society of American Foresters (SAF) as the reestablishment of a tree crop on forest land (Ford-Robertson, 1971). With reforestation there is not necessarily any attempt to restore the same species of trees or the same functions that occurred naturally on the site. Establishment is defined as the process of developing a crop to the stage where it can be considered safe from normal adverse influences such as weeds, browsing, or drought (Ford-Robertson, 1971). Without hydrologic restoration, most projects probably fall within the realm of reforestation or reclamation. On any project, the restorationist is faced with the decision to spend a limited budget to completely restore a small amount of land or to reforest a much larger area.

Wetland creation has two meanings. First, it is "the conversion of a persistent non-wetland area into a wetland through some activity of man" (Lewis, 1990, p. 418). This activity generally includes lowering the surface of an upland sufficiently for the seasonal or permanent exposure of the water table. Conversely, wetland creation can be accomplished by filling a deepwater habitat with dredged materials to a sufficiently shallow depth to support wetland plants. The second kind of wetland creation occurs when an entire ecosystem is first destroyed and then re-created on the same site. Creation in this manner takes place, for example, when a wetland is destroyed during the course of surface mining. Following mining, the original ecosystem is re-created on physically reclaimed land, which requires the ecological engineering of new soils and hydrological conditions, as well as the establishment of a biotic community. The term "constructed wetland" is often used interchangeably with "created wetland" and is apparently coming into preferred usage by many practicing restorationists.

Enhancement is defined as "the increase in one or more values of all or a portion of an existing wetland by man's activities, often with the accompanying decline in other wetland values" (Lewis, 1990, p. 418). Examples of forested wetland enhancement include selective removal of some tree species to favor growth of those species that provide greater values to desired wildlife and diking tracts of bottomland forest so that flooding can be controlled (i.e., construction of green-tree reservoirs). In many cases an enhancement for one species or suite of species proves detrimental to many other species. In contrast to enhancement, the process of ecological restoration is holistic and does not favor individual species or particular ecological functions and values to the detriment of other species or functions.

The Need for Restoration

During the last century, a large amount of the original bottomland hardwood forest area in the United States has been lost. Losses have been greatest in the LMAV and East Texas. Of an estimated 9.7 million ha (24 million acres) of bottomland hardwood forest present in the LMAV at the time of European colonization, only 2.1 million ha (5.2 million acres; 22%) remained by 1978 (MacDonald and others, 1979). Approximately 63% of the original bottomland hardwood forest area in East Texas has been lost (Frye, 1987). Proportionally, the most extreme losses of bottomland hardwood forest have occurred in the northern part of the LMAV; in southern Illinois, about 98% of the original bottomland hardwood forest area has been lost (Tiner, 1984).

The primary cause of bottomland hardwood loss has been conversion of the land to agricultural production. Approximately 87% of wetland losses in the United States as a whole has been attributed to agriculture (Tiner, 1984), and the losses of forested wetlands in the LMAV have corresponded very closely to the expansion of agricultural land (MacDonald and others, 1979). Additional losses of bottomland hardwood forests have been caused by construction and operation of flood control structures and reservoirs, drainage and conversion to pine forests, surface mining, petroleum extraction, and urban development.

While many of these alternative uses of bottomland hardwood forest sites are important economically, the functions and values of intact bottomland hardwood forests (storage of floodwaters, water quality improvement, provision of wildlife habitat, etc.) are becoming increasingly appreciated. These functions and values have been described both in technical terms (Wharton and others, 1982; Taylor and others, 1990; Wilkinson and others,

1987) and in terms readily understood by nontechnically oriented readers (Harris and others, 1984).

Growing public concern over the loss of bottomland hardwood forests and wetlands in general has resulted in unprecedented opportunities for protection of this valuable resource. Clearly, preservation of the existing bottomland hardwood resource—through fee title acquisition, easements, or other means—should be the preferred protection strategy. Given the magnitude of the losses that have already occurred, however, restoration of former bottomland hardwood habitats has become a key element in an overall strategy of protection. Over the past 10 years, at least 62,500 ha (154,000 acres) were reforested within the LMAV. Most of this area was planted by the Natural Resources Conservation Service (through the Wetland Reserve Program) or the U.S. Fish and Wildlife Service, although other state and federal agencies have also been involved in planting bottomland hardwood forests (King and Keeland, 1999). The rate of reforestation has been increasing to the point that the amount of LMAV land scheduled for reforestation by all agencies over the next 5 years totals 74,200 ha (183,300 acres). Although the amount of land being restored is commendable, the continuing losses are staggering. From the mid-1970's to the mid-1980's (the most current data available) a total of 364,200 ha (900,000 acres) of forested wetlands were lost in the LMAV region of Arkansas, Louisiana, and Mississippi. Obviously, we are a long way from our national goal of no net loss.

Restoration and Mitigation

The term "mitigation" in this guide refers to the process of rectifying or compensating for the impact on a wetland of a specific development project. In the strict sense, mitigation is a much broader concept than restoration, including avoidance (no impacts to wetlands) and minimization (project modification to reduce the amount of wetlands to be affected) (40 CFR 1508.20 [1998]). Mitigation is usually required as part of the process of obtaining a permit for a development project, such as a "404" permit (Section 404 of the Clean Water Act) for dredge or fill operations in a wetland. Thus, mitigation refers to activities taking place in a regulatory environment. Restoration in this situation can help achieve no net loss of wetlands, but it is not likely to make a significant contribution to making up for past losses.

Because so much of the bottomland hardwood resource has already been lost, the greatest contributions are likely to be made by restoration projects that are not done as mitigation. Voluntary projects to restore agricultural fields, old unreclaimed surface mines, and other such sites on public and private lands are needed if restoration of bottomland hardwood forests is to be achieved on a scale significant enough to achieve a net gain of wetlands.

Restoration, Ecosystems, and Landscape

This guide contains information that is specific to restoration of forested wetlands of the Southeast and lower Midwest. The best approach to restoration is to maintain the overall integrity of ecosystems, including the entire global ecosystem. In practice, however, most restoration projects are conducted in isolation, on a site-specific basis. It is probable that some opportunities to increase the value of an individual restoration project are simply overlooked because not all restorationists are used to thinking of their projects within an ecosystem or landscape context. Therefore, it is worthwhile to consider individual restoration projects within a larger, long-term context.

Where sufficient flexibility exists, restoration sites should be selected to maximize their usefulness within a larger geographic area. One obvious example is to locate the site where it will have the most beneficial impact on water quality (or other desired function) within a watershed. Prime locations are along the edges of existing streams or rivers, especially where the site will act as a buffer between farm fields and other nonpoint sources of pollution and the waterway. Also, by placing a forested wetland near the lower end of a small watershed, it may act as a filter for runoff and floodwaters from the entire area upstream. By shading the water and increasing inputs of plant debris and invertebrates, restoration sites along waterways will also improve habitat values for fish. In some cases, it might be beneficial to choose a restoration site that can act as a screen between an existing site, such as a marsh used by waterfowl, and a road, housing development, or agricultural area.

Opportunities to maximize wildlife habitat values should also be sought. For instance, choosing sites that will increase the size of an existing but isolated tract may improve habitat for forest interior species and reduce nest predation and parasitism. Many of the species in most need of protection require the interior habitat provided by large tracts. On the other hand, sites that will provide a travel corridor between existing tracts of forest might be more valuable than isolated sites in some cases. Corridors, however, may actually have negative or minimal impacts on some wildlife, and any reader contemplating creating a corridor is urged to look at some of the recent literature on this subject (Simberloff and others, 1992; Hobbs, 1992; Rosenberg and others, 1997; Tiebout and Anderson, 1997).

Those involved in land management and restoration should keep abreast of developments in fields such as conservation, biology, and systems and landscape ecology to the greatest extent possible. By developing an increased appreciation of ecosystem and landscape level processes, land-use planners, managers, and restorationists may be able to greatly increase the environmental values of their projects.

The Environmental Impacts of Restoration

The process of restoration can have both positive and negative impacts on the environment. While it is clear that a successfully restored site is healthier and more desirable than a degraded site, there may well be some hidden environmental costs associated with the restoration process that can call the overall value of the project into question.

One of the most obvious negative impacts associated with restoration is when one wetland is degraded to restore another. Plants or topsoil are sometimes removed from intact wetlands and moved to restoration sites. When this causes significant damage to the intact wetland, then the net benefit of the project must be considered to be significantly reduced. Fortunately, this issue is being addressed by professional restorationists, and especially with the ever-increasing availability of commercially produced seed and seedlings, is becoming less of a problem.

The creation of green-tree reservoirs is a common forested wetland management practice that has been shown to degrade bottomland hardwood stands in the Southeast. A green-tree reservoir is typically flooded in the fall to provide waterfowl habitat and then drained during the next spring. This usually changes the timing, duration, extent, and frequency of flooding within these systems. Although flooding during the dormant season is generally not thought to harm most bottomland hardwood tree species, studies have shown that the repeated flooding of green-tree reservoirs can result in the loss of the less water tolerant species. Quite often, the hard mast producing species that the manager wants to maintain, such as Nuttall, cherrybark, and willow oaks, are the very species killed by this management technique. These more desirable species are often replaced by overcup oak, water hickory, swamp red maple, green ash, and baldcypress. In addition, most green-tree reservoirs in the LMAV are not dewatered on schedule each spring (Judy DeLoach, U.S. Army Corps of Engineers Regulatory Functions Branch, Memphis, TN, oral commun.), further impacting the desirable hard mast species.

Another negative impact associated with some projects is the destruction of a healthy upland site to create a wetland. The net benefit of this type of project, which is often required by regulatory agencies, is highly questionable, especially because of the low degree of certainty that a fully functional, sustainable wetland can actually be created on a former upland site. While this kind of project could conceivably have an overall net benefit in some cases, the decision to destroy an upland site to create a wetland should never be taken lightly.

Hydrologic restoration is encouraged to the greatest extent possible; however, full consideration must be given to the landscape context in which the restoration will be developed. Many river processes, such as erosion, sedimentation, etc., are occurring at an accelerated rate. Floodplain wetlands can be overwhelmed and/or severely degraded if unnatural fluctuations in river flow and unnatural loads of sediment, nutrients, and contaminants in the river are not reduced to approximate predisturbance levels (Humburg and others, 1996; Sparks and others, 1998). In this case, the restored vegetation may be destroyed and the site filled in with sediment to the point where it can no longer be considered a (viable) wetland.

Some restoration projects involve extremely high expenditures for the restoration of relatively small areas. It seems reasonable to consider the opportunity costs associated with such projects. For example, is expending $100,000 or more to restore a small, isolated wetland in an industrial area worthwhile, or would it be better to put that money towards some other environmentally oriented project that might have a larger net benefit? There is no simple way to determine the answers to such questions, but they are still worth considering.

Finally, the costs associated with energy-intensive restoration projects should be considered. Use of heavy earthmoving equipment, irrigation, and other operations associated with restoration projects all require energy, primarily from fossil fuels. Even use of nursery-produced planting stock (versus direct seeding or natural regeneration) may involve a moderately high expenditure of energy. Because production and consumption of fossil fuels and most other forms of energy involve negative impacts to the environment, energy efficiency should be considered when planning a restoration project. Although it should certainly not be used as an excuse for skimping on necessary operations such as good site preparation, energy inputs to restoration projects should be reduced where possible.

Sustainability of Restoration Projects

Restored wetlands are no different than other ecological systems in that they are both naturally dynamic and subject to future human-induced perturbations. Examples of natural changes that might be expected to occur include succession and damage caused by storms, animals, insects, or disease. Examples of human-induced perturbations include changes in hydrology as encroaching development increases runoff into the wetland and long-term changes in global climate effects on local weather patterns.

In cases where there is a desire to limit or control natural change (e.g., to maintain a restoration site in a stage dominated by early to midsuccessional species), long-term management of the site needs to be planned. The silvicultural techniques discussed in Chapter 14 will be the primary tools for most forms of long-term management.

The concept of "freeboard" has been suggested as one way of increasing the sustainability of a restoration site in the face of human-induced changes in hydrology (Willard and Hiller, 1990). This concept is that the restoration site should be designed so that there is room for the desired plant community to shift to higher or lower elevations in response to gradual shifts in the site's hydrology. Wetlands with steep transitions to uplands or steep dropoffs to deep water do not have as much freeboard as sites with long, gentle slopes and therefore should be avoided where possible.

The one certainty about a restoration project is that, as time passes, it will be subjected to both natural and man-made agents of change. Restorationists, therefore, need to consider multiple decades when designing projects and not just project time specified in permits or the lifetime of the first generation of trees.

Selected References

Allen, J.A., and Kennedy, H.A., Jr., 1989, A guide to bottomland hardwood restoration: Slidell, La., U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Research Center and Stoneville, Miss., U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, 28 p.

Allen, J.A., 1997, Reforestation of bottomland hardwoods and the issue of woody species diversity: Restoration Ecology, v. 5, p. 125-134.

Breedlove, B.W., and Dennis, W.M., 1983, Wetlands reclamation: a drainage basin approach, *in* Robertson, D.J., ed., Reclamation and the Phosphate Industry: Proceedings of the Symposium Held at Clearwater Beach, Fla., January 26-28, 1983: Bartow, Fla., Florida Institute of Phosphate Research, p. 90-99.

Council on Environmental Quality, 1998, Mitigation: U.S. Code of Federal Regulations, Title 40, Pt. 1508.20.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats: U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-79/31, 103 p.

Delcourt, P.A., and Delcourt, H.R., 1987, Long-term forest dynamics of the temperate zone, A case study of late-Quaternary forests in eastern North America: New York, Springer-Verlag, 439 p.

Eyre, F.H., ed., 1980, Forest cover types of the United States and Canada: Washington, D.C., Society of American Foresters, 148 p.

Ford-Robertson, F.C., ed., 1971, Terminology of forest science: technology practice and products, The Multilingual Forestry Terminology Series No. 1: Washington, D.C., Society of American Foresters, 349 p.

Forman, R.T.T., 1986, Landscape ecology: New York, John Wiley and Sons, 619 p.

Forman, R.T.T., 1995, Land mosaics: the ecology of landscapes and regions: Cambridge University Press, 632 p.

Frye, R.G., 1987, Bottomland hardwoods: current supply, status, habitat quality and future impacts from reservoirs, *in* McMahan, C.A., and Frye, R.G., eds., Bottomland Hardwoods in Texas: Proceedings of an Interagency Workshop on Status and Ecology, May 6-7, 1986, Nacogdoches: Austin, Tex., Texas Parks and Wildlife Department, p. 24-28.

Hamel, P.B., and Buckner, E.R., 1999, So how far could a squirrel travel in the treetops? A prehistory of the southern forest, *in* Wadsworth, K.G., ed., Transactions of the 63rd North American Wildlife and Natural Resources Conference, 1998, Orlando, Fla., p. 309-315.

Harris, L.D., 1984, The fragmented forest: island biogeography theory and the preservation of biotic diversity: Chicago, The University of Chicago Press, 211 p.

Harris, L.D., Sullivan, R., and Badger, R.L., 1984, Bottomland hardwoods: valuable, vanishing, vulnerable: Gainesville, Fla., Cooperative Extension Service, University of Florida, 17 p.

Hobbs, R.J., 1992, The role of corridors in conservation: solution or bandwagon?: Trends in Ecology and Evolution, v. 7, p. 389-392.

Humburg, D.D., Graber, D.A., Havera, S.P., Fredrickson, L.H., and Helmers, D.L., 1996, What did we learn from the great flood of 1993?, *in* Ratti, J.T., ed., Proceedings of the 7th International Waterfowl Symposium, 1995, Memphis, Tenn., p. 139-148.

Jordan, W.R., III, Gilpin, M.E., and Aber, J.D., 1987, Restoration ecology: a synthetic approach to ecological research: New York, Cambridge University Press, 342 p.

Jordan, W.R., III, Peters, R.L., II, and Allen, E.B., 1988, Ecological restoration as a strategy for conserving biological diversity: Environmental Management, v. 12, no. 1, p. 55-72.

King, S.L., and Keeland, B.D., 1999, Survey of reforestation of southern forested wetlands: Restoration Ecology, v. 7, no. 4, p. 348-359.

Lewis, R.R., III, 1990, Wetlands restoration/creation/enhancement terminology: suggestions for standardization, *in* Kusler, J.A., and Kentula, M.E., eds., Wetland creation and restoration: the status of the science: Washington, D.C., Island Press, 591 p.

MacDonald, P.O., Frayer, W.E., and Clauser, J.K., 1979, Documentation, chronology, and future projections of bottomland hardwood habitat losses in the lower Mississippi alluvial plain: Washington, D.C., U.S. Fish and Wildlife Service, 427 p.

National Research Council, 1992, Restoration of aquatic ecosystems: science, technology, and public policy: Washington, D.C., National Academy Press, 552 p.

National Resources Conservation Service, 1998, Conservation Practices Standard, Wetland Restoration, Code 657: http://www.ftw.nrcs.usda.gov/nhcp_2.html, accessed Nov. 1, 1999.

Naveh, Z., and Lieberman, A.S., 1994, Landscape ecology, theory and application: New York, Springer-Verlag, 360 p.

Putnam, J.A., Furnival, G.M., and McKnight, J.S., 1960, Management and inventory of southern hardwoods: U.S. Department of Agriculture, Forest Service, Agriculture Handbook No. 181, 102 p.

Rosenberg, D.K., Noon, B.R., and Meslow, E.C., 1997, Biological corridors: form, function, and efficacy: Bioscience, v. 47, no. 10, p. 677-687.

Schneider, R.L., Martin, N.E., and Sharitz, R.R., 1989, Impact of dam operations on hydrology and associated floodplain forests of southeastern rivers, *in* Sharitz, R.R., and Gibbons, J.W., eds., Freshwater wetlands and wildlife, CONF-8603101, U.S. Department of Energy Symposium Series No. 61: Oak Ridge, Tenn., U.S. Department of Energy, Office of Science and Technology Information, p. 1113-1122.

Simberloff, D., and Cox, J., 1987, Consequences and costs of conservation corridors: Conservation Biology, v. 1, p. 63-71.

Simberloff, D., Farr, J.A., Cox, J., and Mehlman, D.W., 1992, Movement corridors: conservation bargains or poor investments?: Conservation Biology, v. 6, p. 493-504.

Sparks, R.E., Nelson, J.C., and Yin, Yao, 1998, Naturalization of the flood regime in regulated rivers: Bioscience, v. 48, p. 706-720.

Taylor, J.R., Cardamone, M.A., and Mitsch, W.J., 1990, Bottomland hardwood forests: their functions and values, *in* Gosselink, J.G., Lee, L.C., and Muir, T.A., eds., Ecological processes and cumulative impacts: illustrated by bottomland hardwood wetland ecosystems: Chelsea, Mich., Lewis Publishers, Inc., p. 13-86.

Tiebout, H.M., III, and Anderson, R.A., 1997, A comparison of corridors and intrinsic connectivity to promote dispersal in transient successional landscapes: Conservation Biology, v. 11, no. 3, p. 620-627.

Tiner, R.W., Jr., 1984, Wetlands of the United States: current status and recent trends: Newton Corner, Mass., U.S. Fish and Wildlife Service, 59 p.

U.S. Army Corps of Engineers, 1987, Corps of Engineers wetlands delineation manual, Wetlands Research Program Technical Report Y-87-1: Vicksburg, Miss., Waterways Experiment Station, U.S. Army Corps of Engineers, 165 p.

Wharton, C.H., Kitchens, W.M., Pendleton, E.C., and Sipe, T.W., 1982, Ecology of bottomland hardwood swamps of the Southeast: a community profile: U.S. Fish and Wildlife Service, Biological Services Program FWS/OBS-81/37, 133 p.

Wilkinson, D.L., Schneller-McDonald, K., Olson, R.W., and Auble, G.T., 1987, Synopsis of wetland functions and values: bottomland hardwoods with special emphasis on eastern Texas and Oklahoma: U.S. Fish and Wildlife Service, Biological Report 87(12), 132 p.

Willard, D.E., and Hiller, A.K., 1990, Wetland dynamics: considerations for restored and created wetlands, *in* Kusler, J.A., and Kentula, M.E., eds., Wetland creation and restoration: status of the science: Washington, D.C., Island Press, p. 459-466.

Chapter 2: General Planning Considerations

A successful restoration project starts with good planning. In general, the plan should define the goals for restoration and subsequent management of the project site and should identify specific procedures to meet the goals. The major steps in the planning process are (1) identify goals; (2) characterize the restoration site; (3) select species to be restored; (4) develop a design for the site; (5) determine site preparation needs; (6) determine best regeneration method(s); (7) determine what postregeneration operations will be carried out; (8) develop a timetable for obtaining planting stock, equipment, and personnel; (9) develop a budget and identify the source of funds; and (10) develop specific performance standards for evaluating project success. Some of these steps are discussed in this chapter while all are covered in more detail throughout the manual.

Project Goals, Objectives, and Success Criteria

Ideally, restorationists should begin their projects by developing a list of general goals or long-term objectives. General goals might include something like (1) establishment of a bottomland forest similar in species composition to the original forest or (2) establishment of a forested wetland that will provide wintering habitat for mallards and wood ducks.

Once general goals have been listed, more specific objectives can be developed. An example of a specific objective is a list of the species to be established and the number of each to be planted per hectare (acre). Another specific objective might be that the site should either flood naturally or have the capability of being flooded artificially during the winter months so that waterfowl can feed within the forest. Much time, effort, and money can be wasted on a project if objectives are not specified in the planning stage, yet simply developing a set of objectives is not sufficient. Specific performance criteria should also be developed to help assess whether the objectives are being met.

Frequently, project objectives are limited to the establishment of vegetation. Success criteria for these projects are often simple, such as the survival rate of all species planted should be at least 50% after one complete growing season, or a minimum of 980 trees per ha (400 per acre) of preferred species should be established on the site; the trees should be at least 2 m (~6 ft) tall and have been growing on the site for at least 24 months.

Therefore, specific goals or objectives and success criteria ideally should be established for all elements of the restoration project. In addition to vegetation, it is desirable to establish criteria for soils, hydrology, water quality, and fish and wildlife habitat. The Mitigation Site Type classification system (MiST; White and others, 1990) provides both general and specific success criteria for bottomland hardwood restoration projects (table 2.1). Although these criteria are directed toward mitigation, they can serve as a starting point for developing more specific success criteria for a given project. The MiST is recommended reading for all restorationists involved with bottomland hardwood and other forested wetland systems. In many ways the planning process from an overall landscape perspective is an artistic process and deserves optimum time and attention to detail before moving forward toward implementation.

Project Site Design

The level of effort put into project site design can vary considerably. For small projects that do not involve extensive earthmoving or are not being carried out for mitigation, the design may simply be what a restorationist envisions. For larger, more complex projects, the process of site design may involve development and review of a series of engineering drawings depicting surface contours, structural specifications, and locations of various forest types to be planted (fig. 2.1). Regardless of the level of detail in the final design, the process of site design should only begin after project objectives have been determined and the site evaluation is completed.

The three-stage design process outlined in the Soil Conservation Service's (now the NRCS) Engineering Field Handbook (Soil Conservation Service, 1992a) is appropriate for the design of restoration projects. Their first step, data collection and evaluation, is analogous to the site evaluation process described in Chapter 3.

The second stage is the development of a preliminary design, which consists of (1) developing a list of the general project features; (2) identifying any structures needed; and (3) developing a preliminary layout of the site (e.g., contours, location of any stream channels, and location/area of vegetation types to be established). The preliminary design may consist of a variety of alternatives and should be sufficiently detailed to allow for a well-informed choice of alternatives based on both ecological and economic grounds.

The third stage is development of the final design, which consists of (1) assessment of the accuracy of the data used in the preliminary design; (2) review of the accuracy of all drawings developed in the preliminary design; (3) selection of alternatives; (4) development of final drawings depicting site layout and any structures; and, ideally, (5) production of a report covering both the

Table 2.1. General definitions of mitigation success used in the Mitigation Site Type classification system (MiST) (see White and others, 1990 for more information).

General definitions of mitigation success
Vegetation Successfully mitigated project sites shall contain: (1) An approved species composition represented by self-sustaining species populations. (2) Adequate tree abundance in terms of overall density and spatial distribution throughout the project site. (3) Well-established trees (e.g., trees should have been growing on site for at least 1 year). (4) An adequate representation of undergrowth species.
Soil A succ successfu definitions of the current U.S. Army Corps of Engineers Wetland Delineation Manual.
Hydrology , duration, and seasonality of the flooding or soil saturation and the source of the water.
Water quality Water q of the frequency distribution of the reference site when graphically represented. Minimally, measured levels of parameters should not violate State or Federal water quality standards.
Fish and wildlife habitat Because of the long-term nature of forested wetland restoration, the habitat for fish and wildlife will be considered restored if the success criteria for vegetation, soils, and hydrology are met.

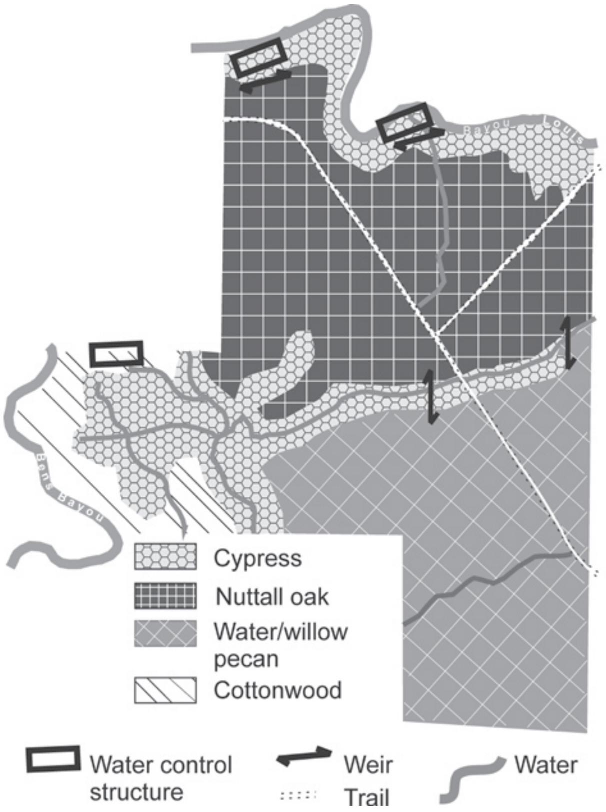

Figure 2.1. Engineering drawings depicting surface contours, structural specifications, and locations of various forest types to be planted can be helpful when designing a restoration project.

final design and a plan for any relevant operation, maintenance, and monitoring.

Review and approval by a licensed civil engineer may be required for designs of structures and surface contours. Local NRCS officials and relevant regulatory agencies should be contacted to determine what regulations apply to restoration project designs.

Regeneration Method

Several regeneration methods have been used effectively to restore bottomland hardwood forests. These methods include direct seeding, planting seedlings, planting cuttings, and transplanting saplings or larger trees. Natural regeneration and topsoiling (the spreading of topsoil from a healthy wetland over a restoration site to introduce seeds and other propagules) are other options that are effective in some cases and should also be considered. Regeneration methods are described in more detail in Chapters 7, 8, 9, and 10.

The final choice of regeneration method should be based on a thorough knowledge of the advantages and disadvantages of each method, characteristics of the species to be planted, condition of the site, availability of planting stock, personnel, equipment requirements, and costs. It is worth noting that, on many restoration projects, combinations of planting methods have been used effectively. For instance, direct seeding might be used as a primary method for regenerating trees, while topsoiling could be employed to introduce understory species, and seedlings of some difficult to establish tree species could be planted.

Decisions about regeneration methods on a given project should be made well in advance of the planting date to ensure the availability of suitable planting stock. If planting is scheduled for late fall through spring, then the choice of planting methods should ideally be made the previous spring or summer for small sites (smaller than about 8 ha [~20 acres]), and even earlier for large sites.

In a survey of federal and state agencies involved in restoring/reforesting bottomland hardwood sites, King and Keeland (1999) found that nearly half of the restorationists experienced problems obtaining sufficient seed of the desired species, and that greater than 80% were unable to obtain the required number of seedlings. In many cases the restorationists were forced to use substitute species. For example, a general shortage of ash seedlings in 1998 forced restorationists to search for seedlings of a variety of other species as replacements.

Obtaining Planting Stock

In most cases, it is best to obtain planting stock from existing suppliers; exceptions will occur most frequently in the cases of large-scale or long-term restoration programs or when using cuttings, transplants from the wild, or direct seeding. A large number of suppliers operate in the region covered by this guide, including state forestry commission nurseries, private nurseries, and both large- and small-scale seed suppliers (see Appendix C for a partial listing of suppliers).

In general, it is best to obtain planting stock as locally as possible. If purchasing planting stock from a local supplier, be sure that their seed was collected from an acceptable (local) source, which will help ensure (but not guarantee) that the stock is adapted to the region where the planting will take place. It may also help reduce damage to planting stock from shipping. Also, nurseries may need lead time greater than 1 year for unusually large orders of seed or seedlings.

Personnel Requirements

Project planning and supervision should be carried out by well-qualified personnel. The project manager should know which specific technical skills are needed to design a project (e.g., forestry, plant ecology, civil engineering, hydrology) and should take the necessary steps to ensure that skilled personnel are available for each task.

It is also important to ensure that personnel who actually implement the project in the field have the requisite skills and are closely supervised. Personnel may be required for skilled (and sometimes dangerous) tasks, such as heavy machinery operation and herbicide application, and for simpler tasks, such as tree planting. The temptation exists to hire an inexpensive, untrained labor force that is poorly supervised, especially for the simpler tasks. The success of some projects has been drastically reduced, however, by the use of poorly trained and inadequately supervised personnel (table 2.2).

Equipment

Some of the equipment needed for restoration projects is described in the following chapters. Actual equipment needs will obviously vary, depending on type of site preparation needed, planting method(s) used, etc. The restorationist should determine in advance what equipment will be needed and take steps to ensure its availability at the appropriate time. Table 2.3 lists some of the equipment that may be required for a restoration project.

Timing of Project Operations

The need to plan in advance for the acquisition of equipment and planting stock has already been mentioned. In addition, careful planning of the overall operations of the project is required.

Forested wetlands typically have periods where the soil is too wet for heavy equipment to operate. Even if the equipment can operate under wet site conditions, this practice should be avoided in order to minimize compaction and soil erosion. Dry seasons, usually in late summer or fall over most of the area covered by this guide, are a good time to do most of the jobs that involve

Table 2.2. Seven "grievous errors" that have been made on restoration projects in the absence of adequate training and supervision (Clewell and Lea, 1990).

1. Vigorous saplings were loaded at a nursery into open trucks and delivered to a project site dead from windburn and desiccation. The unsupervised planting crew planted the dead trees.
2. Potted trees were delivered on a Friday afternoon and allowed to roast in the direct summer sun before being planted dead on Monday.
3. Gallon-sized trees were removed from flat-bottomed pots and planted in holes dug with pointed spades. Air pockets remained beneath their root balls and stressed or killed many saplings.
4. Nurseries shipped trees of the wrong species, the error was either unnoticed or unreported, and the trees were planted.
5. Mesic trees were planted in hydric sites.
6. Cuttings of willows and cottonwoods were planted upside down.
7. Project sites were not fenced or staked, and work crews planted up to 40% of their seedlings on adjacent land.

Table 2.3. Partial list of equipment occasionally used in restoration projects and examples of how they are used.

Equipment	Use(s)
Dragline	Excavation; removal of topsoil
Scraper	Removal, segregation, and transport of soil and/or overburden
Bulldozer	Removal and spreading of soil and/or overburden; surface contouring
Dump truck	Transport of topsoil
Front-end loader	Removal of soil and/or overburden; loading trucks
Tractor	Site preparation; planting; weed control; fire lane construction
Rippers, chisel, plows, offset disks	Reduction of soil compaction; preparation of soil surface for planting
Mechanical seed planter	Direct seeding
Mechanical seedling planter	Planting bare-root seedlings
Gasoline-powered soil auger	Planting containerized seedlings
Tree spade	Transplanting saplings and larger trees
Dibble bar, sharpshooter shovel	Hand planting seedlings
Backpack sprayer	Weed and exotic plant control
Brushhook, machete	Vine control

earthmoving or other site preparation jobs requiring heavy equipment.

In some cases, sufficient time must be allowed between site preparation and planting so that the soil can settle, the hydrology can be double-checked, a green manure crop can be planted and plowed under, and so on. For relatively complex restoration projects, a schedule of operations should be prepared and approved by key personnel involved in project planning and implementation.

Selected References

Brown, D., 1977, Handbook: equipment for reclaiming strip mined land: Missoula, Mont., U.S. Department of Agriculture, Forest Service, 58 p.

Clewell, A.F., and Lea, R., 1990, Creation and restoration of forested wetland vegetation in the southeastern United States, *in* Kusler, J.A., and Kentula, M.E., eds., Wetland creation and restoration, the status of the science: Washington, D.C., Island Press, p. 195-231.

Duryea, M.L., and Dougherty, P.M., 1991, Forest regeneration manual: Boston, Mass., Kluwer Academic Publishers, 433 p. [Although this guide is for southern pine regeneration, it will still give the reader a very good overview of many of the operations involved in forest restoration.]

Kentula, M.E., Brooks, R.P., Gwin, S.E., Holland, C.C., Sherman, A.D., and Sifneos, J.C., 1992, An approach to improving decision making in wetland restoration and creation, *in* Hairston, A.J., ed.: Corvallis, Ore., U.S. Environmental Protection Agency, Environmental Research Laboratory, 151 p.

King, S.L., and Keeland, B.D., 1999, Survey of reforestation of southern forested wetlands: Restoration Ecology, v. 7, no. 4, p. 348-359.

Marble, A.D., 1992, A guide to wetland functional design: Boca Raton, Fla., Lewis Publishers, 240 p.

Myles, D.V., 1978, A compendium of silvicultural equipment, Forest Management Institute Information Report FMR-X-115: Ottawa, Canada, Canadian Forestry Service, Environment Canada, 233 p.

Soil Conservation Service, 1992a, Engineering field handbook, Part 650, Chap. 5, *in* Stanley, W.R., compiler, Preparation of engineering plans: Washington, D.C., U.S. Department of Agriculture, Soil Conservation Service, p. 5-1 to 5-23.

Soil Conservation Service, 1992b, Engineering field handbook, Chap. 13, Wetland restoration, enhancement, or creation: Washington, D.C., U.S. Department of Agriculture, Natural Resources Conservation Service, 79 p.

U.S. Army Corps of Engineers, 1987, Corps of Engineers wetlands delineation manual, Wetlands Research Program Technical Report Y-87-1: Vicksburg, Miss., Waterways Experiment Station, U.S. Army Corps of Engineers, 165 p.

White, T.A., Allen, J.A., Mader, S.F., Mengel, D.L., Perison, D.M., and Tew, D.T., 1990, MiST: a methodology to classify pre-project mitigation sites and develop performance standards for construction and restoration of forested wetlands: results of an EPA-sponsored workshop: Atlanta, Ga., U.S. Environmental Protection Agency, 85 p.

Chapter 3: Evaluation of the Site

Site is a central concept in the practice of forestry and forest restoration. The term “site” is rarely defined precisely but may be interpreted as being synonymous with the term “habitat.” It refers to the place in which trees grow and encompasses both the abiotic (nonliving) and biotic (living) factors that may have an impact on the survival and growth of the trees. The size of an area that is considered one site can vary considerably, as long as the critical environmental factors remain relatively the same.

The term “project site” is used occasionally in this guide. In some cases the project site may be homogeneous enough to be considered as one site in the ecological sense of the word. In other cases, variation within the project site, such as different degrees of flooding, different soil types, slope, aspect, existing vegetation, etc., may require that it be treated as a number of smaller sites, each of which may have different site preparation needs, specific levels of suitability for different species, and so on.

In this chapter, it is assumed that the site to be restored has already been chosen. It is expected that the choice of sites will be limited in most cases, either for legal reasons (e.g., permit requirements that a specific area be restored after surface mining) or for management-related objectives (e.g., the desire to provide a travel corridor for wildlife between two large blocks of forest). The principles described in this chapter, however, can also be used to select a site for restoration.

Once the site is identified, the first task is to conduct a site evaluation. Site evaluation can be informal, involving no more than a windshield survey, or it can be much more elaborate (and expensive), involving the development of ecological baseline information by means of prerestoration monitoring (e.g., hydrology) and analytical testing (e.g., soil characteristics). The intensity of the evaluation will depend on factors such as the restorationist’s prior experience with similar sites, the degree to which the site has been altered, and available funds. At a minimum, the site should be walked over or traveled by ATV to confirm the restorationist’s expectations from various sources (e.g., NRCS soil survey, etc.). Whatever the intensity of the evaluation, the abiotic and biotic factors described in this chapter should be considered.

Abiotic Site Factors

The most important abiotic factors to be considered in bottomland areas are climate, hydrology, and soils. These three factors interact with each other but are treated separately in this section.

Climate

Climate is one of the major factors affecting tree species distribution and the growth of individual trees. The primary climatic factors operating on trees are precipitation (amount and distribution), temperature regime, and evapotranspiration.

Although climate is critical, it is generally not the most important aspect of a site evaluation as long as the species to be established are within their natural range. There is little or no practical need for a detailed climatic assessment if the planting stock is known to be well adapted to the area. Knowledge of the normal variation in local climate could be very important, however, as the success of any plantings could be adversely affected by extremes of temperature and/or precipitation (i.e., drought or flooding) during the first year or two after planting.

The consideration of climate becomes most important when the introduction of a species not indigenous to the area—or a different subspecies or provenance of an indigenous species—is contemplated. In such cases, it is important to know the general climatic characteristics of the site (see table 3.1), but it may be even more important to know the climatic extremes that can occur. Forestry literature is replete with examples of species introductions that were successful until some natural but uncommon event occurred, such as a prolonged drought or flood, an unusually long, deep freeze, or an ice storm. By definition, nonnative species should not be used in restoration projects.

Table 3.1. Abiotic site data that should be obtained if possible.[1]

Climate	Hydrology	Soils
Mean annual rainfall	Mean annual flood duration	Degree of soil saturation
Mean monthly rainfall	Mean growing season flood duration	Presence of pans or depressions
Mean monthly temperature	Mean growing season water table depth	Degree of mottling
Evapotranspiration potential	Hydrologic system	Percent organic matter
Incidence of droughts, extreme cold, extreme heat, ice storms, and hurricanes	Topographic position	Soil type, texture, structure, depth, pH, compaction, and color

[1] Where mean data is specified above, it is also desirable to obtain an indication of variability (e.g., standard deviations).

Occasionally, microclimate can be an important consideration, but this is less often the case on bottomland sites than on upland sites, where slope and aspect may greatly affect the temperature and moisture regime. The exposed nature of most restoration sites, which can result in hotter and drier conditions than in adjacent mature forested wetlands, must be considered. Frost pockets—low, concave areas that tend to trap cold air—are also sometimes a problem within restoration sites at relatively high elevations. Such areas are not likely to occur on large floodplains, but where present, frost pockets may result in direct damage to trees or may literally uproot seedlings by the process of frost heaving.

Hydrology

Hydrology is the most important factor affecting the local distribution of bottomland tree species within their natural ranges. Hydrology as treated in this guide refers to the frequency, duration, depth, seasonality, and source of flooding and/or soil saturation that occur on a site, as well as the depth of the water table.

Detailed hydrologic data, such as the first three items listed in table 3.1, will often not be available for a given site but should be obtained to the greatest extent possible. The U.S. Geological Survey's Water Resources Division provides real-time hydrologic data online at http://water.usgs.gov. In most cases, the restorationist will have to make do with knowing only the hydrologic system type and the topographic position of the site. Fortunately, much can be inferred about a site's hydrologic characteristics from this information.

The main hydrologic systems in the the lower Midwest and southeastern United States are large alluvial rivers, minor stream bottoms, blackwater rivers (those originating in the Coastal Plain), spring-fed streams, isolated basins, backwater swamps, bogs, and seep areas. Different hydrologic systems can have very different flooding patterns (fig. 3.1). Large alluvial rivers tend to have longer periods of high water, with most of the flooding occurring between November and May. Minor stream bottoms and blackwater rivers tend to have more erratic flooding, since these smaller systems are more responsive to local precipitation. Spring-fed streams, bogs, and seeps tend to have much more stable hydrologic patterns, and groundwater table levels assume greater importance than overbank flooding.

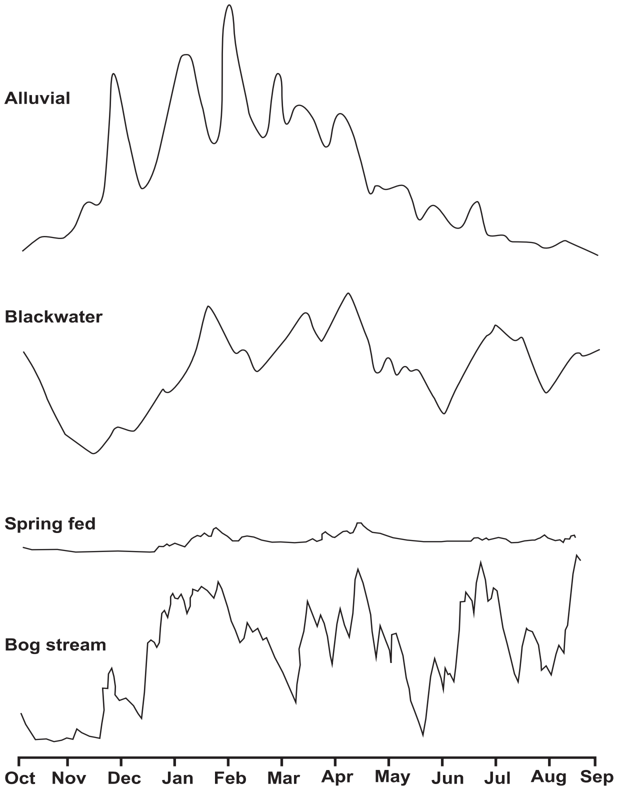

Figure 3.1. Hydrographs of typical bottomland hardwood sites (redrawn from Wharton and others, 1982).

Topographic positions within floodplains include sloughs, natural levees, lower floodplain or first bottoms, terraces, and slopes (transitional areas to uplands; fig. 3.2). The depth and seasonality of flooding, as well as numerous other site characteristics, varies substantially with topographic position. Other sites such as cypress domes support forested wetlands somewhat similar in nature to bottomland hardwoods. These wetlands typically occur as isolated basins rather than within a riverine floodplain.

It is important to realize that hydrologic alterations have occurred at most sites. Drainage and flood control projects, diversions of flows, pumping from aquifers, road construction, and numerous other developments are so ubiquitous that nearly every site has a hydrologic regime different than it had 50-100 years ago. A tract of mature forest in the immediate vicinity can be very informative. If the existing overstory trees in the tract look stressed, or the understory trees are mostly either less or more flood tolerant than the overstory trees, then there may have been substantial hydrologic modifications to the site. Hydrologic records, maps, aerial photos, and interviews with people knowledgeable about the site may all be used to determine what types of hydrologic changes have taken place. It may be impossible to restore a site's hydrology back to historic conditions.

In cases where the natural hydrologic pattern of a site has been altered drastically, or for areas that are not naturally bottomland hardwood sites, more specific hydrologic information may be necessary. Along

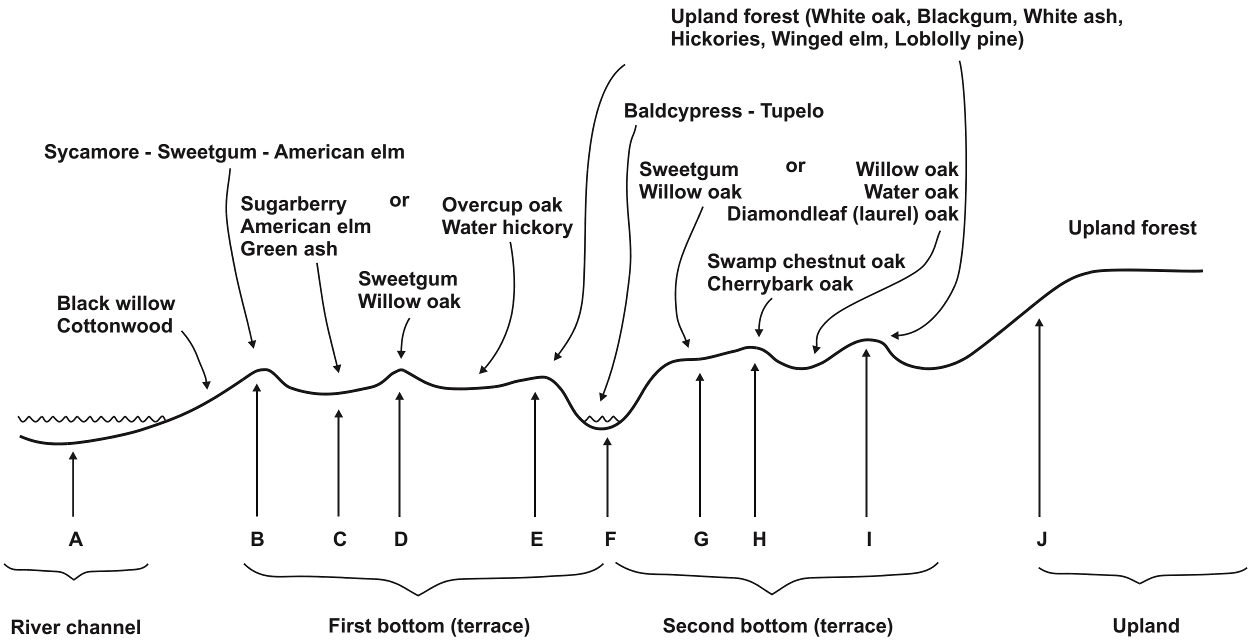

Figure 3.2. Topographic positions and associated forest cover types within a river floodplain (modified from Wharton and others, 1982).

reservoir shorelines, for example, water levels may fluctuate dramatically, and seasonal patterns of flooding and drawdown need to be understood in detail. In areas where heavy machinery has been operated, topsoil has been displaced, or water control structures have been installed, surface flooding and/or water table levels may vary considerably from an undisturbed site. On the most heavily disturbed sites, such as surface-mined areas that have been regraded, it is advisable to collect as much detailed information as is available or even to monitor the hydrologic regime of the site prior to selecting species and initiating planting (see Chapter 13).

Soils

Alluvial bottomland soils generally have more clay and organic matter than upland soils, and therefore they tend to have higher moisture-holding capacity, fertility, and productivity. There are numerous exceptions and potential soil-related problems, however, and an appreciation of soil conditions is important for ensuring the success of a restoration project.

A good place to start evaluating the soils on a site is with the county or parish soil survey. Even if the site has been drastically altered, county or parish soil surveys can provide information on the soil originally found on the site. Soil surveys should be used with caution, however, since the information on forested wetland sites is usually much less detailed than information on adjacent agricultural lands. In many instances, the mapped soil type within a wetland may include one to several areas of a different soil type. Soil surveys are available for most of the counties and parishes covered by this guide and can be obtained from local NRCS offices (also see NRCS National Soil Survey Center data at http://www.statlab.iastate.edu/soils/nssc). The restorationist should know what soil series are present on the project site and be familiar with their basic characteristics. A list of some of the soil characteristics that are often important to know and which are for the most part available in soil surveys is provided in table 3.1.

Soil texture (relative amounts of sand, silt, and clay) is basic information for a restorationist because texture affects other soil characteristics important for tree survival and growth and also because it may greatly affect planting operations. In particular, heavy clay (and organic soils) can present difficulties for planting operations.

Soil moisture characteristics are also critical (see hydrology section, this chapter). In addition to the hydrology data listed in table 3.1, soil color and mottling can provide good indications of the degree of soil saturation. Dark, dull soils (i.e., those with low chroma values) indicate prolonged soil saturation. Soils that are somewhat less saturated may contain brightly colored mottles.

Although soil surveys can provide much information, they are not a substitute for an on-site examination or for soil testing, especially if the site has been heavily disturbed. If there is evidence of soil compaction (e.g., signs of overgrazing, ruts caused by heavy machinery, lots of puddles), it would be worthwhile to determine the bulk density of the soil. Most bottomland hardwood trees will not grow well if bulk density exceeds 1.4 g/cm^3, and they may not survive if the bulk density exceeds 1.7 g/cm^3. Soil penetrometers (fig. 3.3), or simple soil probes, can be used as a quick means to assess the degree of compaction.

On some sites, in particular areas that have been surface-mined for coal, soil pH assumes great importance. Soil pH on these sites may be below 4.0 to 4.5, which is the lower limit that most bottomland species apparently tolerate. Soil can also be too alkaline. Some riverfront soils along the Mississippi and Red Rivers have pH values of 7.5-8, and this degree of alkalinity has probably been responsible for the failure of planting trials with oak species such as Nuttall and cherrybark. Sites mined for phosphate may also have a pH in excess of 7, which is high enough to affect the survival and growth of some bottomland hardwood species.

Figure 3.3. Soil penetrometer being used to assess soil compaction.

Nutrient deficiencies are generally not a problem on bottomland sites, except where soils have been drastically disturbed (e.g., by surface mining or topsoil removal) or have been in agricultural production over long time periods. In such cases, nitrogen is likely to be deficient. Nutrient deficiencies may be detected by soil tests. Guidelines for soil sampling, testing, analysis, and interpretation can be found in some of the references at the end of this chapter.

Biotic Site Factors

Four biotic factors may affect the success of a restoration project: plant competition (including competition from exotic species), animals, insects, and disease.

Plant Competition and Exotic Species

Competition from other plants for light, water, or nutrients may reduce the survival and growth of planted trees. Although there have been cases where the partial shade caused by competing vegetation actually increased survival of planted trees—and planted trees will usually win out over weeds given enough time—competition generally reduces both overall survival and initial growth. In addition, a heavy plant cover can (1) interfere with tree planting operations, (2) provide habitat for small rodents and other animals that can consume planted seeds or seedlings, and (3) serve as fuel for wildfire. It is therefore important to evaluate the current plant cover on the restoration site and also attempt to determine what type of plant competition may occur after planting.

Certain types of plants can be particularly harmful to planted trees. A heavy growth of vines, for example, can shade tree seedlings and their weight can cause bending or physical damage. Some exotic weeds, such as Johnson grass, Vasey grass, and cogongrass grow so tall and thick that they can reduce growth and significantly increase mortality of planted trees. Fescue, bahia grass, and other turf-forming grasses that are commonly planted for pasturage and erosion control often compete successfully against young planted trees for water during times of drought.

The amount and type of weeds that can be tolerated on a site before or after planting depends on the objectives of the project and the planting methods being considered. There is rarely a need to quantify the weed cover precisely, but it is useful to know if weeds cover much of the site, how tall the weedy vegetation is, and what dominant species are present.

An attempt should be made to determine in advance what type of plant competition may arise after planting. This determination will aid in the planning and budgeting of postplanting operations and can be accomplished by examining similar restoration sites, reviewing available literature, the NRCS Plants Database (http://plants.usda.gov/), or talking to people with knowledge of the area (such as county foresters or agricultural extension agents).

In many restoration projects done as mitigation, there is a requirement that no more than a certain percentage of the total plant cover (typically 5-10%) consists of exotic species. Therefore, a special effort needs to be made to determine in advance what types of exotic plants are likely to become established and what control measures will be necessary. Exotic species of particular concern include melaleuca, Brazilian pepper, and cogongrass in peninsular Florida. Elsewhere, nuisance exotic species may include Chinese tallow, Japanese honeysuckle, kudzu, multiflora rose, wild grapes, and various turf grasses.

Animals

Both domestic animals and various wildlife species may damage or destroy planted trees. The animals most likely to cause damage to planted seeds or seedlings include deer, raccoons, beaver, nutria, small rodents, cattle, and hogs. The restorationist should therefore find out if any of these animals are present in numbers large enough to affect tree species selection or to make specialized protection measures necessary. An accurate appraisal of deer damage may best be obtained by requesting the assistance of a wildlife biologist from the state wildlife agency.

Field personnel need to be trained to look for and recognize animal damage in potential restoration sites (Larry Savage, Louisiana Department of Wildlife and Fisheries, oral commun.; Waller and Alverson, 1997) because grazing can affect the long-term species composition of the site. In the bottomland hardwoods of southern Illinois, deer browsing on planted oaks and natural sugarberry have resulted in an overabundant advanced regeneration of the less palatable sweetgum and boxelder (Larry Savage, Louisiana Department of Wildlife and Fisheries, oral commun.). Boerner and Brinkman (1996, p. 309) reported that "deer browsing was more important than environmental gradients or climate factors in determining seedling longevity and mortality." Seedlings that are fertilized and irrigated in nurseries are especially preferred by browsing deer.

Rodents have caused extensive mortality to restoration projects that have used direct seeding. Savage and others (1996) reported successful seedling establishment by seeding willow oak acorns at rates 62% higher than normal (5,982 per ha [2,420 per acre]) in spite of extensive damage caused by rice and cotton rats. In areas subject to long-term flooding, nutria and beaver have been especially damaging. Nutria can decimate baldcypress regeneration and are a major factor limiting baldcypress regeneration in swamp forests of Louisiana (Conner and others, 1986). Damage to baldcypress usually consists of pulling up the seedling and eating the bark from the taproot. Although seedling protectors have proven successful in some studies, they have not been universally successful and add substantially to the cost of planting.

Insects and Disease

Numerous injurious insects and diseases affect bottomland hardwood tree species. Many of these agents can drastically lower the value of trees for timber production, but seldom will they cause the total failure of a restoration project. Most cases where insects or disease destroyed large numbers of planted seeds or seedlings occurred when the trees planted were not well suited to the site and were therefore heavily stressed. Although it will generally not be a problem, the potential for insect or disease outbreaks should be investigated any time the restorationist is working in an unfamiliar area.

Human Influences

In addition to abiotic and biotic factors, restorationists should assess the potential for human impacts on the restoration site. Among other things, people may use the site as a play area, drive over it in off-road recreational vehicles or farm machinery, accidentally douse it with herbicides from nearby farm or forestry operations, burn it with a carelessly thrown cigarette, or intentionally vandalize it.

Some indirect human influences are much less obvious but can still cause the total failure of a restoration project. For example, residual herbicides applied to previous agricultural crops can stunt or kill many tree species. Some tree planting failures in the Lower Mississippi Alluvial Valley have repeatedly occurred on fields where milo was grown the previous year, and the effect of residual herbicides was a prime suspect. Although the effect of residual herbicides has not been demonstrated experimentally, it cannot be ruled out as a possible influence on restoration success.

Selected References

Baker, J.B., and Broadfoot, W.M., 1979, A practical method of site evaluation for commercially important southern hardwoods: New Orleans, La., U.S. Forest

Service, Southern Forest Experiment Station, General Technical Report SO-26, 51 p.

Boerner, R.E.J., and Brinkman, J.A., 1996, Ten years of tree seedling establishment and mortality in an Ohio deciduous forest complex: Bulletin of the Torrey Botanical Club, v. 123, p. 309-317.

Conner, W.H., Toliver, J.R., and Sklar, F.H., 1986, Natural regeneration of baldcypress (*Taxodium distichum* (L.) Rich.) in a Louisiana swamp: Forest Ecology and Management, v. 14, no. 4, p. 305-317.

Haynes, R.J., Allen, J.A., and Pendleton, E.C., 1988, Reestablishment of bottomland hardwood forests on disturbed sites: an annotated bibliography: U.S. Fish and Wildlife Service Biological Report, v. 88, no. 42, 104 p.

Hodges, J.D., 1994, The southern bottomland hardwood region and brown loam bluffs subregion, *in* Barrett, J.W., ed., Regional silviculture of the United States (3rd ed.): New York, John Wiley and Sons, p. 227-269.

Messina, M.G., and Conner, W.H., 1998, Southern forested wetlands: ecology and management: Boca Raton, Fla., Lewis Publishers, 616 p.

Pritchett, W.L., and Fisher, R.F., 1987, Properties and management of forest soils (2nd ed.): New York, John Wiley and Sons, 494 p.

Savage, L., Anthony, J., and Buchholz, R., 1996, Rodent damage to direct seeded willow oak in Louisiana, *in* Eversole, A.G., ed., Proceedings of the Fiftieth Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, Oct. 5-9, 1996, Hot Springs, Ark.: Southeastern Association of Fish and Wildlife Agencies, p. 340-349.

Smith, D.M., 1986, The practice of silviculture (8th ed.): New York, John Wiley and Sons, 527 p.

Waller, D.M., and Alverson, W.S., 1997, The white-tailed deer: a keystone herbivore: Wildlife Society Bulletin, v. 25, no. 2, p. 217-226.

Wharton, C.H., Kitchens, W.M., Pendleton, E.C., and Sipe, T.W., 1982, Ecology of bottomland hardwood swamps of the southeast: a community profile: U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-81/37, 133 p.

Chapter 4: Species Selection

Tree species selection is one of the more critical phases of a restoration project. An inappropriate choice can result in a total planting failure, an inadequately stocked and underproductive forest, or a forest of minimal value for wildlife.

The choice of species to be planted depends on the project goals, the characteristics of the site, and the availability of planting stock, equipment, and personnel. An informed choice also requires knowledge of the silvical characteristics (see Burns and Honkala, 1990a,b, "Silvics of North America, Volumes 1 and 2") and uses of bottomland hardwood tree species (Putnam and others, 1960).

There is no standard or widely recommended procedure for selecting the species to be planted. Assuming the goal of the project is full restoration and the site has not been irreversibly modified, information about the original forest composition of the site, or of a nearby forest with similar site characteristics (see reference sites section, this chapter), should be used as the basis from which to begin the selection process. Once the restorationist has an idea of the original forest composition (keeping in mind that forest composition is continually changing), then he or she can begin to narrow the number of species to be planted. Species selected must be tolerant of the soils and hydrological conditions on the project site. Flood tolerant tree species (e.g., Nuttall oak or green ash) can be planted in areas that rarely flood, but less flood tolerant species cannot survive in flood prone areas.

Tree species that are likely to colonize the restoration project site by natural dissemination of seeds or other propagules need not be planted, or at least not in great numbers. Assuming a nearby seed source exists, such species generally include sweetgum, sycamore, and the common species of maple, elm, and ash. These species fruit prolifically almost every year and produce fruits that are carried great distances from parent trees by the wind. In contrast, heavy fruited species such as most oaks and hickories should be planted. Such species may produce mast prolifically only once in several years, and their dispersal mechanisms are weak or unreliable.

If the primary purpose of the restoration is for wildlife habitat, fast growing species such as cottonwood or sycamore can be planted to provide some vertical structure within a few years. These species can attain heights of 10 m or more within 3 to 4 years and could provide Neotropical migratory bird habitat during the early developmental stage of the restoration. As these fast growing trees begin to provide vertical structure, their use by birds will assist in increasing biodiversity through the introduction of numerous seeds (Twedt and Portwood, 1997). An additional consideration, especially on private land, might be the market value of cottonwood or sycamore for pulp within 10 years. Schweitzer and others (1999) reported on an experimental cottonwood plantation that was used to provide a financial return to the landowner within 10 years while acting as a nurse crop to Nuttall oak seedlings. Such innovative plantings can provide multiple benefits, including the development of improved soil structure and increased organic matter, while the long-term target vegetation (the underplanted seedlings such as oak) are developing. Upon harvest, some of the cottonwood trees can be retained to provide future sawlogs or den trees.

To assist with the process of species selection, several types of information are provided here. Selected silvical characteristics and wildlife-related uses of 69 bottomland hardwood species are listed in table 4.1. Supplemental information on species associations and ecological relationships, based on the Society of American Foresters cover types listed in table 1.1, is provided in Appendix A. Additional information on matching species and soil types in the Midsouth is supplied in Appendix D, and for the Southern Atlantic Coastal Plain, information is in Appendix E. Also, several references to more detailed treatments of individual species or other aspects of species selection are provided at the end of this chapter (page 34).

Reference Sites

The concept of a "reference wetland" has been used for several years by professionals involved in wetland restoration and creation for mitigation purposes. Using the reference wetland approach, data are collected on the plant community, hydrology, and other characteristics of a natural, relatively undisturbed wetland on a site similar to and in the vicinity of the proposed mitigation site. These data are then used as a basis for designing the mitigation project and judging its success.

Because of the high degree of variability within natural bottomland hardwood forests, the use of a "reference forest ecosystem" has been proposed. A reference forest ecosystem has been defined as a conceptual forest selected for creation or restoration. It is based on forested wetlands represented locally (in the same or a nearby watershed) in terms of species composition and physiognomy. The key difference between a reference forest ecosystem and a reference wetland is that a reference wetland is a specific wetland, whereas a reference forest ecosystem is a composite description from several similar forested wetlands.

Table 4.1. Characteristics of selected tree and shrub species suitable for reforestation in bottomland hardwood forests of the southeastern United States: typical habitat; flood and shade tolerance; seed ripening and storage requirements; reproductive characteristics; and suitability for direct seeding, wildlife food and habitat, and wood products.

Key to Flood Tolerance:

T (tolerant) —Species are able to survive and grow on sites where soil is saturated or flooded for long periods during the growing season. Species have special adaptations for flood tolerance.

MT (moderately tolerant) —Species are able to survive saturated or flooded soils for several months during the growing season, but mortality is high if flooding persists or reoccurs for several consecutive years. These species may develop some adaptations for flood tolerance.

WT (weakly tolerant) —Species are able to survive saturated or flooded soils for relatively short periods of a few days to a few weeks during the growing season; mortality is high if flooding persists longer. Species do not appear to have special adaptations for flood tolerance.

I (intolerant) —Species are not able to survive even short periods of soil saturation or flooding during the growing season. Species do not show special adaptations for flood tolerance.

		Tolerance		Seed	
Species Name	Habitat	Flood	Shade	ripening	Seed storage requirements[1]
Ash, green *Fraxinus pennsylvanica*	First bottoms and newly deposited sediments except in deep swamps. Most common on flats or shallow sloughs.	MT	Adult = I; Seedling = MT to T	Sept.- Oct.	Sealed container at 41°F (5°C) and 7-10% seed moisture.
Ash, pumpkin *Fraxinus profunda*	Widely distributed on new sediments, in first bottoms, and edges of swamps. Similar to green ash.	T	Adult = I to MT; Seedling = MT	Oct. - Dec.	Sealed container at 41°F (5°C) and 7-10% seed moisture.
Ash, white *Fraxinus americana*	Widely distributed; however, limited to ridges and high hummocky flats of older alluvium, outwashes from uplands, and creek bottoms.	WT	Adult = I; Seedling = MT	Sept. - Dec.	Sealed container at 41°F (5°C) and 7-10% seed moisture.
Bay, loblolly *Gordonia lasianthus*	Swamps, bays, and wet sites in pine barrens of Coastal Plain.	MT	T to I	Sept. - Dec.	Unknown.
Bay, red *Persea borbonia*	Borders of swamps in rich, moist, mucky soil and wet pine and hardwood flats and bays. Not on alluvial sites.	MT	T	Sept. - Oct.	Unknown.
Bay, swamp *Persea palustris*	Pine barrens, swamp margins, and river bottoms.	MT	T	Unknown	Unknown.
Bay, sweet *Magnolia virginiana*	Edges of headwater and muck swamps and pocosins.	MT	MT	July - Oct.	Store in sealed container at 32-41°F (0-5°C). Seeds stored at higher temperatures should not be cleaned.
Beech, American *Fagus grandifolia*	Mostly creek bottoms and occasionally in minor river bottoms and on ridges of old alluvium or terraces.	I	VT	Sept. - Nov.	Store loosely in sealed polyethlyene bags from fall until February of the following winter at 20-30% moisture and 33-41 °F (1-5 °C).

Key to Shade Tolerance:
In some cases a range of tolerance is given depending on the so
others, 1960 and Burns and Honkala, 1990.
Adult —Refers to the shade t
Seedling —Refers to the shade tolerance of seedlings.
VT (very tolerant) —Species are able to survive and thrive in the deep shade of a closed canopy forest.
T (tole
MT (moderately tolerant) —Species will
WT (weakly tolerant) —Species will grow with partial shad
overtopping competition.
I (Intolerant) —Species require open conditions and full sunlight for normal growth and development.
Key to Suitability:
H = high
M = medium
L = low
I = insufficient data to determine suitability or unsuitability

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Germination best on bare, moist soil in openings. Excellent natural seed dispersal. Sprouts well.	I	L	L	I	M
Seedlings establish on bare, moist soil after water has drained off. Sprouts well from stumps.	I	L	L	I	M
Seedlings establish best in openings on bare, moist soil after water has drained off. Sprouts prolifically from stumps.	I	L	L	I	H
Seedlings establish best in relatively open areas with exposed soil.	I	L	L	I	I
Seedlings establish in both understory and openings. Fire stimulates germination. Sprouts well from stumps.	I	L	L	I	L
Seedlings establish both in understory and openings. Sprouts well from stumps.	I	I	I	I	L
Seedlings establish both in shade and especially in openings and heavy thinnings.	I	L	L	I	L
Regeneration is generally sparse but persistent. Seedlings establish best in shade on moist, well-drained soil. Sprouts well from roots and stumps.	I	L	M	I	L-M

Species Name	Habitat	Tolerance Flood	 Shade	Seed ripening	Seed storage requirements[1]
Birch, river *Betula nigra*	Near river fronts and banks of minor streams. Not below Memphis in the Delta but extends to the coast on secondary streams.	MT	I	May - June	Store at 1-3% moisture content and 36-38 °F (2-3 °C).
Blackgum *Nyssa sylvatica*	Throughout bottoms on ridges and high flats of older silty alluvium. Well drained, silty and loamy soils.	WT	I to WT	Sept. - Oct.	Store over winter in cold, moist sand or in cold storage.
Boxelder *Acer negundo*	Scattered throughout riverfronts of major streams, bottomlands, ridges, and high flats.	MT	MT to T	Aug. - Oct.	Air dry to a moisture content of about 10-15% before storage.
Buttonbush *Cephalanthus occidentalis*	Mostly in Gulf of Mexico coastal plains and Delta. Also in swamps along streams and margins of ponds.	T	T	Sept. - Oct.	Unknown.
Cherry, black *Prunus serotina*	Sparsely scattered throughout on oldest alluvium and outwash from uplands. Often in hammocks.	I	I to MT	Late Aug.-Sept.	Unknown.
Cottonwood, eastern *Populus deltoides*	Mostly on newly deposited soil along major streams, recently abandoned fields, right-of-ways, clean burns, wet spots in pastures, and banks of small drainages and ditches.	WT - MT	VI	May - Aug.	Air dry 4 days at room temperature. Store in stopper vials at 36-40°F (2-4 °C).
Cottonwood, swamp *Populus heterophylla*	Scattered in shallow swamps, in deep sloughs, along often flooded creek bottoms, and on wet spots on low hammocks on the east coast.	MT	I to WT	Apr. - July	Cold storage of 41°F (5 °C) and 5-8% moisture content.
Cypress, bald (baldcypress) *Taxodium distichum*	Very poorly drained organic or clay soils. Swamps, deep sloughs, borders of old lake beds, very wet areas with up to 3 m (10 ft) of flooding. Commonly originates as dense, even-aged stands.	VT	I to WT	Oct. - Dec.	Seeds keep well in dry storage of 41 °F (5 °C) for at least one winter.
Cypress, pond (pondcypress) *Taxodium distichum* var. *nutans*	Shallow piney woods, headwater and/or back swamps, perched ponds, sloughs, and wet flats on lower Coastal Plain, mostly east of the Mississippi River.	T	I	Oct. - Dec.	Seeds keep well in dry storage of 41 °F (5 °C) for at least one winter.
Dogwood, flowering *Cornus florida*	Common in bottoms of minor streams and on well-drained sites.	I	VT	Sept. - Oct.	Store cleaned seeds in sealed containers at 38- 41 °F (3-5 °C) for 2-4 years.

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Seedlings establish on moist, well-drained soils. Rapid early growth from seed.	I	L	L	I	L
Sparse regeneration. Germination and establishment only on dry soil. Stumps to 30 cm (12 inches) sprout well.	I	M	M	I	L
Germinates best on moist, bare, mineral soil in shade or openings. Sprouts well from stumps.	I	L	H	I	L
Very moist seed bed is optimum. Stumps of all sizes sprout.	I	M	L	I	L
Seeds establish in bare mineral soil or in leaf litter. Sprouts from stumps.	I	L	M	I	H
Germination best on wet mineral soil. Continued moisture and top light imperative. Sprouts well from stumps up to 30 cm (12 inches).	I	L	M	I	H
Reproduction is erratic and sparse. Germination best on bare, moist, mineral soil. Rapid early growth. Sprouts from stumps up to 30 cm (12 inches).	I	L	M	I	L
Generally poor regeneration but occasionally excellent in openings. Best germination on very moist muck substrate. Sprouting inconsistent from stumps up to 50 cm (20 inches).	I	L	L	I	H
Similar to baldcypress.	I	L	L	I	M
Germination best on bare mineral soil in understory or openings. Stumps of all sizes sprout well.	I	L	H	H	L

Species Name	Habitat	Tolerance		Seed ripening	Seed storage requirements[1]
		Flood	Shade		
Dogwood, rough-leafed *Cornus drummondii*	Dry to very wet sites and on soils that range from sand to clay.	T	T	Aug. - Oct.	Store cleaned seeds in sealed containers at 38- 41 °F (3-5 °C) for 2-4 years.
Elm, American *Ulmus americana*	Common on flats in newer alluvium.	MT	MT to T	Late Feb. - June	Store at 3-4% moisture content in sealed containers at 25°F (-4 °C).
Elm, cedar *Ulmus crassifolia*	High flats, poorly drained ridges, usually on impervious silty clay soils.	MT	MT to T	Sept. - Oct.	Air dry and store at 39 °F (4 °C) in sealed containers.
Elm, slippery *Ulmus rubra*	Occasionally on banks of secondary streams.	I	T	Apr. - June	Sealed containers.
Elm, water *Planera aquatica*	Swamps, deep sloughs or low, poorly drained flats. Usually found on clay soils covered with water for part of the year.	T	T	Early spring	Unknown.
Elm, winged *Ulmus alata*	Ridges and high flats of older alluvial soils and terraces. Generally in creek bottoms and hammocks.	WT - I	T	April	Air dry and store at 39°F (4 °C) in sealed containers.
Hackberry *Celtis occidentalis*	Common on flats and river fronts of new alluvium but not in deep swamps.	MT	MT to VT	Sept. - Oct.	Store in sealed container at 41°F (5 °C) for up to 5 ½ years without losing viability.
Hawthorn *Crataegus* spp.	Dry, sandy, stony ridges to moist river bottoms and in margins of swamps.	MT	I	July - Nov.	Unknown.
Hickory, shagbark *Carya ovata*	Moderately well-drained loams.	WT	MT	Sept. - Oct.	Same as for water hickory.
Hickory, shellbark *Carya laciniosa*	On river terraces and on loamy flats in second bottoms. Also grows well on clay and silt loams, dry and sandy soils.	WT	VT	Sept. - Nov.	Same as for water hickory.
Hickory, water (bitter pecan) *Carya aquatica*	Common to flats, sloughs, and margins of swamps of major alluvial streams. Poorly to moderately well-drained clays and loams.	MT	MT	Sept. - Nov.	Store at 41 °F (5 °C) in closed containers for 3 to 5 years. Storage for one winter is achieved by stratification.
Pecan, sweet *Carya illinoinensis*	Current or recent river fronts on moderately well-drained loams.	WT	I to MT	Sept. - Oct.	Store at 41 °F (5 °C) in closed containers for 3 to 5 years. Storage for one winter is achieved by stratification.

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Seedlings establish best on moist soil under partial shade. Sprouts well from stumps.	I	L	H	H	L
Germination and establishment on surface of moist mineral soil or on undisturbed humus; seldom on bare areas. Stumps up to 33 cm (13 inches) sprout well. Seeds remain viable submerged for a month.	I	M	M	M	L-M
Seedlings establish in shade or in openings on moist, bare mineral soil. Stumps up to 30 cm (12 inches) sprout well.	I	M	M	M	L
Seedlings establish in shade or in openings on moist, usually well-drained soil. Stumps up to 30 cm (12 inches) sprout well.	I	M	M	M	L
Seedlings establish after water recedes. Sprouts well from stumps.	I	M	L	M	L
Seedling establishment prolific in new openings but sparse in understory. Stumps up to 30 cm (12 inches) sprout well.	I	M	M	M	L
Seedlings often become established in full shade but cannot withstand submergence. Sprouts well from stumps up to 30 cm (12 inches).	I	L	L-M	H	M
Does not readily establish seedlings. Trees are good sprouters.	I	L	M-H	M-H	I
Seedlings require moderately moist seedbed. Sprouts well from stumps.	L	I	M	I	L
Needs moist soil for germination and establishment in understory and openings. Sprouts well from stumps.	I	L	M	I	L
Prolific regeneration in full sunlight. Seedlings are more common in new openings but also occur in understory. Sprouts well from stumps to 50 cm (20 inches).	L	L-M	L	I	L
Adequate regeneration in small or partial openings. Seedlings establish best under about an inch of loamy soil.	M	H	H	I	H

Species Name	Habitat	Tolerance Flood	Tolerance Shade	Seed ripening	Seed storage requirements[1]
Holly, American *Ilex opaca*	Minor stream bottoms and on high ridges of oldest alluvium.	WT	VT	Sept. - Oct.	Store in sealed container.
Honeylocust *Gleditsia triacanthos*	Scattered in large bottoms on all sites except swamps and sloughs. Grows best on the better ridges of new alluvium.	MT	I	Sept. - Oct.	Seeds will retain viability for several years when stored in sealed containers at 32-45 °F (0-7 °C).
Hophornbeam, eastern *Ostrya virginiana*	Slopes and ridges, occasionally in bottoms.	I	T to VT	Late Aug. - Oct.	Unknown.
Hornbeam, American *Carpinus caroliniana*	Rich, moist loams.	MT	VT	Aug. - Oct.	Store at 35-49 °F (2-9 °C) in moist sand, sand and peat, or soil for up to 2 years.
Magnolia, southern *Magnolia grandiflora*	On old alluvium and outwash areas. More common in minor or secondary stream bottoms, hummocks, and wet flats.	WT	T	July - Oct.	Store in sealed containers at 32-41 °F (0-5 °C). Seeds stored at higher temperatures should not be cleaned.
Maple, Florida *Acer barbatum*	Drained sites in secondary bottoms.	WT	T	March - April	Unknown.
Maple, silver *Acer saccharinum*	On riverfronts and streambanks on moderately well-drained loams.	MT	I to T	April - June	Air dry to 30% moisture content before storage.
Maple, swamp red *Acer rubrum*	Common on low, wet flats and edges of headwater swamps.	MT	T	April - June	Air dry to a moisture content of about 10-15% before storage.
Mulberry, red *Morus rubra*	Common on heavy, moist but well-drained soils in first bottoms.	WT - I	T to VT	June - Aug.	Store dry seeds at subfreezing temperature of about -10 to 0 °F (-23 to -17 °C).
Oak, bur *Quercus macrocarpa*	On better flats and low ridges of older alluvium and tributary bottoms north of latitude of Memphis. Commonly found on limestone ridges.	I	WT	Aug. - late Nov.	White oak group
Oak, cherrybark *Quercus pagoda*	Widely distributed on the best loamy sites on all river-bottom ridges and all better drained creek bottoms and hammocks. Predominantly on older alluvium.	WT - I	I	Sept. - Nov.	Red oak group
Oak, delta post *Quercus stellata* var. *mississippiensis*	Large bottoms of the lower Mississippi River. Well-drained, silty clay and loam sites on older alluvium.	WT - I	WT	Sept. - Nov.	White oak group

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Seedlings occur in understory and openings. Sprouts well from stumps.	I	L	L	I	L
New seedlings are usually found in openings and rarely in the understory. Sprouts well from stumps.	I	L	L	H	L
Seedlings establish best on moist mineral soil in understory and in openings. Sprouts well from stumps of all sizes.	I	L	L	I	L
Seedlings establish best on moist mineral soil in understory and in openings. Sprouts well from stumps of all sizes.	I	L	L	I	L
Usually good seed crops but low germination. Sprouts well from stumps.	I	L	L	M-H	L-M
Germinates best on moist mineral soil in shade or openings. Sprouts well from stumps.	I	L	I	I	L
Seedlings occur on bare mineral soil in shade or especially in openings. Sprouts well from stumps.	I	L	H	I	M
Germinates best on moist mineral soil in shade or openings, often after water recedes. Sprouts well from stumps.	I	L	M	I	L
Seedlings occur in shade or openings. Sprouts well from stumps.	I	L	M-H	H	M
Germination may be prolific in open bottomland areas. Seedlings are often killed if flooded during the growing season. Sprouts well from stumps and following burning of small trees, but the quality of sprouts is usually poor.	I	L	H	I	H
Good regeneration with full light but never prolific. Poor quality stump sprouts.	H	H	H	I	H
Good regeneration with light but seldom prolific. Seedlings most common in openings. Not a good stump sprouter.	I	I	H	I	H

Species Name	Habitat	Tolerance Flood	Tolerance Shade	Seed ripening	Seed storage requirements[1]
Oak, laurel (diamondleaf) *Quercus laurifolia*	Near the coast on wet flats, margin of swamps, low clay ridges, or even low sandy loam ridges of blackwater streams.	WT - MT	I - T	Sept. - Oct.	Red oak group
Oak, live *Quercus virginiana*	Usually in well-drained loams and sandy soils along the coast but also may occur in heavier clays.	WT - T	I	Sept. - Dec.	White oak group
Oak, Nuttall *Quercus nuttallii*	Flats, low ridges, shallow sloughs, and margins of swamps in recent alluvial sites, and heavy, poorly drained clays and clay loams. Strictly limited to bottoms of major streams entering the gulf and their larger tributaries.	MT	I	Sept. - Oct.	Red oak group
Oak, overcup *Quercus lyrata*	Widely distributed on poorly drained, heavy soils of major alluvial bottoms. Prevalent in sloughs, on margins of swamps, and in backwater areas.	MT	WT	Sept. - Nov.	White oak group
Oak, pin *Quercus palustris*	In first bottoms and terraces on wet flats with heavy, poorly drained to moderately well-drained clays or clay loams.	MT	I	Sept. - Dec.	Red oak group
Oak, Shumard *Quercus shumardii*	Restricted to well-drained ridge soils in older alluvium and outwash from uplands and to well-drained creek bottoms and hammocks.	WT	I	Sept. - Oct.	Red oak group
Oak, swamp chestnut *Quercus michauxii*	Common in large creek bottoms and hammocks on best, well-drained loamy ridges. Occasionally on a wet, silty clay, high flat.	WT	I to WT	Sept. - Oct.	White oak group
Oak, swamp white *Quercus bicolor*	Extreme northern part of the lower Mississippi Valley, mainly in smaller bottoms on sites with pervious but poorly drained mineral soils.	MT	WT	Sept. - Oct.	White oak group
Oak, water *Quercus nigra*	Widely distributed on loam ridges in first bottoms and on any ridge and silty clay flats in second bottoms or terraces. Moderately well-drained silty clays and loams.	WT - MT	I	Sept. - Nov.	Red oak group

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Regeneration erratic but plentiful with light. Seedlings establish in shade or openings but require release. Sprouts when cut or burned.	I	H	H	I	L
Germination best on moist, warm soil. Sprouts well from roots.	M	H	H	I	L
Acorns remain viable in water for up to 311 days. Seedlings establish in openings or shade but die soon under shade. Seedlings are killed by flooding during the growing season. Stumps of young trees sprout readily.	H	H	H	I	M
Germination is best on moist mineral soil in open or shade but dies under continued shade. Seedlings may be killed by high water during first growing season. Sprouts from small stumps only.	M	M	H	I	L
Seedlings become established in understory openings, but many are killed by flooding during the growing season. Seedlings among most tolerant of oaks. Sprouts well from stumps of small trees.	H	H	H	I	L
Seedlings establish best in full light. Overall poor quality of sprouts but better on young trees.	H	M-H	H	I	H
Germination best on moist, well-drained soils with light cover of leaves. Seedlings require full sunlight for best development. Seedlings are intolerant of flooding. Sprouts from small stumps.	M	M	H	I	H
Regeneration is adequate to sparse, never prolific. Sprouts well from stumps.	I	I	M	I	M
Seedlings establish best on moist, well-aerated soil under leaf litter. Prolonged submergence of seedlings during the growing season is fatal. Sprouts readily from young stumps.	H	H	H	I	M

Species Name	Habitat	Tolerance		Seed ripening	Seed storage requirements[1]
		Flood	Shade		
Oak, white *Quercus alba*	Widely distributed on well-drained loams of the oldest alluvium. Common in better drained creek bottoms above the lower Coastal Plain.	I - WT	WT	Sept. - Nov.	White oak group
Oak, willow *Quercus phellos*	Widely distributed on ridges and high flats of major streams. Less common in creek bottoms. Moderately well-drained silty clays and loams.	WT - MT	I	Aug. - Oct.	Red oak group
Pawpaw *Asimina triloba*	Rich soils along streams and in bottoms.	I	VT	Aug. - Sept.	Unknown.
Persimmon, common *Diospyros virginiana*	Scattered widely on wet flats, shallow sloughs, and swamp margins on poorly drained clays and heavy loams. Rare in creek bottoms.	MT	VT	Sept. - Nov.	Clean, dry seeds should be stored in sealed containers at 41 °F (5 °C).
Poplar, yellow *Liriodendron tulipifera*	Mainly on high quality, well-drained terrace site and outwashes of minor streams. Not primarily a bottomland species.	I	I to VI	Aug. - Oct.	Store dried seeds in sealed cans or plastic bags at 36-40°F (2-4°C) for 3 to 4 years. Moist storage in outdoor soil pits or drums of moist sand in cold storage at 36°F (2°C).
Possumhaw *Ilex decidua*	Margins of swamps, streams, and in rich upland soils.	MT	VT	Early autumn	Unknown.
Sassafras *Sassafras albidum*	Scattered widely on any well-drained site, especially moist but well-drained sandy loam soils.	I	I	Aug. - Sept.	Store in sealed containers at 35-41° (2-5 °C).
Sugarberry *Celtis laevigata*	Common on flats and river fronts of new alluvium but not in deep swamps.	MT	T to VT	Sept. - Oct.	Store in sealed container at 41°F (5°C) for up to 5 ½ years without losing viability.
Swampprivet *Forestiera accuminata*	Swamps, wet flats, and other low lying areas.	T	T	Summer	Unknown.
Sweetgum *Liquidambar styraciflua*	On almost all but the wettest sites. Best developed on clay loam ridges of newer alluvium.	MT	I	Sept. - Nov.	Store at a moisture content of about 10-15% in sealed bags at 35-40 °F (2-4 °C) for up to 4 years.

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Germination best on moist, well-drained soil under direct light. Seedlings intolerant of flooding. Sprouts well from stumps and following fire damage.	M	H	H	I	H
Germination best in full light on moist, well-aerated soil with light leaf litter. Sprouts from young stumps.	H	H	H	I	M
Seedlings establish well in shade or openings. Sprouts well from stumps.	I	L	I	I	L
Seedlings establish mainly in the understory but also in openings. Sprouts readily from stumps and roots.	I	L	H	I	M
Seedlings establish best on moist seedbeds of exposed mineral soil and survive only in full sunlight. Seedlings cannot tolerate flooding. Sprouts readily from stumps.	I	L	L	I	H
Seedlings occur in understory and especially in partial openings. Sprouts well from stumps.	I	L	L	H	L
Germination sparse but is best on moist, loamy soil with litter. Grows well in openings. Sprouts well from roots and stumps.	I	L	L	M-H	L
Seedlings often become established in full shade but cannot withstand submergence. Sprouts well from stumps up to 30 cm (12 inches).	I	L	L-M	H	M
Germination is best in moist mineral soil. Sprouts well from stumps.	I	L	L	I	L
Germination is best on mineral soil in the open. Sprouts well from roots and stumps.	I	M	L	H	M

Species Name	Habitat	Tolerance		Seed ripening	Seed storage requirements[1]
		Flood	Shade		
Sycamore *Platanus occidentalis*	Widely distributed on fronts of major streams and on banks of minor streams, generally on moderately well-drained loams.	MT	WT to I	Sept. - Oct.	Short-term storage in ventilated open-mesh bags. For longer storage, dry to 10-15% moisture content and store in sealed containers at 20-38°F (-7 to 3°C).
Tupelo, Ogeechee *Nyssa ogeche*	Limited to backwater streams and coastal swamps.	T	I	July - Aug.	Store over winter in cold, moist sand or in cold storage.
Tupelo, swamp *Nyssa sylvatica* var. *biflora*	Nonalluvial muck and coastal swamps, seepage areas of upland, and on edges of secondary and minor bottoms.	T	I to WT	Aug. - Oct.	Store over winter in cold, moist sand or in cold storage.
Tupelo, water *Nyssa aquatica*	Swamps and floodplains of alluvial streams.	VT	I to WT	Sept. - Oct.	Store over winter in cold, moist sand or in cold storage.
Walnut, black *Juglans nigra*	Scattered on well-drained loamy sites, typically a creek bottom species.	WT	I	Sept. - Oct.	Clean seed, 20-40% moisture content at 37°F (3 °C) for 1 year in plastic bags or 50% moisture content in screen container buried in pits for up to 5 years.
Waterlocust *Gleditsia aquatica*	Swamps, sloughs, and wet flats.	MT	I	Aug. - Oct.	Seeds will retain viability for several years when stored in sealed containers at 32-45 °F (0-7 °C).
Willow, black *Salix nigra*	Margins and batture of sloughs of principle rivers, also on ditch banks and swamp margins.	T	VI	June - July	Wet seeds may be stored up to a month if refrigerated in a sealed container.
Willow, sandbar *Salix exigua*	Along river margins, on newly formed, low bars and towheads.	MT	VI	Apr. - May	Wet seeds may be stored up to a month if refrigerated in a sealed container.

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[1] See seed handling section, C . Seeds from the red oak group can be stored for up to about 6 months. Seed storage for longer than 6 months should be dry, in sealed containers at 32-36 °F (0-2 °C), but viability loss will be significant.

Reproductive characteristics	Direct seeding	Waterfowl food	Deer/turkey food	Neotropical migrant	Wood products
Seedlings establish best on moist mudflats or other exposed mineral soils, never in shade. Seedlings remain viable in water for 1 month. Sprouts well from stumps.	I	L	L	I	M
Germination and establishment occurs in openings on bare mud when the water recedes.	I	M	M	I	L
Germination best in openings on moist seedbed. Seeds remain viable for months in water. Sprouts well from stumps. Sprouts produce viable seed within 2 years.	I	L-M	L-M	I	L-M
Need full sunlight for germination. Seeds remain viable for months in water. Stump sprouts produce viable seeds within 2 years.	I	L-M	L	I	L-M
Seedlings are mainly found in forest openings but are intolerant of flooding. Sprouts well from small stumps.	I	L	L	I	H
New seedlings are usually found in openings and rarely in the understory. Sprouts well from stumps.	I	L	M	I	L
Germination best on very moist, exposed mineral soil. Seeds will germinate in water. Sprouts well from stumps of small trees. Intolerant of competition.	I	L	H	M-H	M
Germination best on very moist, exposed mineral soil. Seeds will germinate in water. Seedlings more flood tolerant than mature trees. Sprouts well from stumps of small trees. Intolerant of competition.	I	L	H	I	L

An inherent difficulty with using either reference wetlands or reference forest ecosystems is that forested wetland restoration projects are long-term efforts. Thus, many years will pass before the restoration project can be compared to the reference. Still, the process of characterizing similar natural wetlands in the vicinity of the restoration site is useful for species selection and for developing success criteria (see Chapter 2).

Selected References

Baker, J.B., and Broadfoot, W.M., 1979, A practical method of site evaluation for commercially important southern hardwoods: New Orleans, La., U.S. Forest Service, Southern Forest Experiment Station, General Technical Report SO-26, 51 p. [A useful method for matching species to site if good information on soil characteristics is available.]

Banks, R.C., McDiarmid, R.W., and Gardner, A.L., 1987, Checklist of vertebrates of the United States, the U.S. Territories, and Canada: Washington, D.C., U.S. Department of the Interior, Fish and Wildlife Service, Resource Publication 166, 79 p.

Broadfoot, W.M., 1976, Hardwood suitability for and properties of important midsouth soils: New Orleans, La., U.S. Forest Service, Southern Forest Experiment Station Research Paper SO-127, 84 p.

Burns, R.M., and Honkala, B.H., eds., 1990a, Silvics of North America, v. 1, conifers: U.S. Department of Agriculture, Forest Service, Agriculture Handbook 654, 675 p.

Burns, R.M., and Honkala, B.H., eds., 1990b, Silvics of North America, v. 2, hardwoods: U.S. Department of Agriculture, Forest Service, Agriculture Handbook 654, 877 p.

Dirr, M.A., 1990, Manual of woody landscape plants: their identification, ornamental characteristics, culture, propagation, and uses: Champaign, Ill., Stipes Publishing Co., 1007 p.

Hamel, P.B., and Buckner, E.R., 1998, So how far could a squirrel travel in the treetops? A Prehistory of the Southern Forest: Transactions of the 63rd North American Wildlife and Natural Resources Conference, March 20-25, 1998, Orlando, Fla: Washington, D.C., Wildlife Managment Institute, p. 309-315.

Haynes, R.J., Allen, J.A., and Pendleton, E.C., 1988, Reestablishment of bottomland hardwood forests on disturbed sites: an annotated bibliography: U.S. Fish and Wildlife Service Biological Report 88(42), 104 p.

Martin, A.C., Zim, H.S., and Nelson, A.L., 1951, American wildlife and plants: a guide to wildlife food habits: New York, Dover Publications, Inc., 500 p.

Putnam, J.A., Furnival, G.M., and McKnight, J.S., 1960, Management and inventory of southern hardwoods: U.S. Department of Agriculture, Forest Service, Agriculture Handbook No. 181, 102 p.

Raifaill, B.L., and Vogel, W.G., 1978, A guide for revegetating surface-mined lands for wildlife in eastern Kentucky and West Virginia: U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/84, 89 p.

Schweitzer, C.J., Gardner, E.S., and Stanturf, J.A., 1999, A comparison of large scale reforestation techniques commonly used on abandoned fields in the lower Mississippi Alluvial Valley, *in* Haywood, J.D., ed., Proceedings of the 10th Biennial Southern Silvicultural Research Conference, February 16-18, 1999, Shreveport, La.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-30, p. 136-141.

Twedt, D.J., and Portwood, J., 1997, Bottomland hardwood reforestation for Neotropical migratory birds: are we missing the forest for the trees?: Wildlife Society Bulletin, v. 25, no. 3, p. 647-652.

White, T.A., Allen, J.A., Mader, S.F., Mengel, D.L., Perison, D.M., and Tew, D.T., 1990, MiST: A methodology to classify pre-project mitigation sites and develop performance standards for construction and restoration of forested wetlands: results of an EPA-sponsored workshop: Atlanta, Ga., U.S. Environmental Protection Agency, 85 p.

Chapter 5: Site Preparation

The main purpose of site preparation is to create suitable growing conditions for tree seeds or seedlings. On sites with minimal disturbance, preparation may consist solely of improving soil structure and reducing the existing plant cover and debris by disking, mowing, or burning. Site preparation may also involve other treatments, such as fertilization, modifications of the site's hydrology, replacing topsoil, or large-scale earthmoving.

Another function of site preparation is to create improved conditions for the use of mechanical planting equipment, which is often necessary following logging (because of all the logging slash, fallen snags, etc.) and is sometimes important in other cases, such as on surface mine sites, where grading may be required.

Site preparation is not always necessary and in some cases may hinder the invasion of woody species. In a study of natural invasion of woody seedlings onto abandoned agricultural fields, Allen and others (1998) found significantly more seedlings in areas that had not been disked. The effects of disking on the long-term survival of seedlings that did become established, however, was not examined in that study, and most studies have shown that site preparation will improve the survival and growth of planted seeds or seedlings. Even though site preparation can add a considerable amount to the costs of restoration, it should never be ignored if the site evaluation indicates it is needed.

Site Preparation on Old-Field Sites

A common type of restoration site is abandoned agricultural land. Since old-field sites are generally well suited for growing agricultural plants, they often require only minimal site preparation to grow trees and other forest vegetation. Trees have often been planted successfully on old fields with virtually no site preparation. The method of regeneration is a key factor in determining the level and type of site preparation on old fields. For example, if seedlings are to be mechanically planted, then the site should not be disturbed unless there is substantial soil compaction (see Restoring Soil section, this chapter). Crop stubble and/or standing weeds should be left alone because they tend to provide better support for the tractor. If seedlings are to be hand planted, then crop stubble should be left standing, but standing weeds in fallow fields should be mowed. For machine planting of acorns on heavy clay soils, the site should be double disked the fall prior to planting to prevent cracking of the soil along the furrow lines during dry weather. If acorns are planted on silty or lighter soils not prone to cracking, the site can be planted without tilling.

Restoring Hydrology

Before any restoration project can be considered complete, the hydrology must be restored to approximate some historic pattern of flooding. As mentioned previously, hydrological records, maps, aerial photos and personal interviews can provide information about hydrologic changes that have taken place. The hydrologic regimes of many old-field sites in the southern United States have been altered either by localized drainage efforts such as ditching or tiling or by larger scale drainage or flood control projects. Some fields are still subject to frequent flooding, although the flooding may not be as deep or as long in duration as it was originally. Other fields flood much less frequently or not at all. In some cases, flooding has been increased by large-scale projects. For example, the Atchafalaya Basin of southern Louisiana is now used as a floodway for a portion of the Mississippi River flow. As such, the bottomland hardwood forests in this area are subjected to increased frequency, duration, and depth of flooding, and they are further subjected to greatly increased sedimentation. The restorationist must also remember that the hydrologic regime refers to groundwater dynamics, soil saturation, and periods of low flow, not just to overbank flooding.

When localized drainage is the primary factor, it may be possible to restore hydrology to its original or an otherwise suitable condition by plugging ditches, removing tiles, building or removing dikes, or some similar manipulation. In many cases, only a portion or portions of a levee or dike will have to be removed, rather than spending the time, effort, and money to remove the entire structure. The remaining portions of the levee will provide topographic relief and increase biodiversity by supporting a different forest community type. In areas where land-leveling has removed ridge and swale topography, a complete restoration will require use of earthmoving equipment to restore surface microtopography and hydrology. Interpretation of historic aerial photography can often provide locations of natural swales and other topographic high and low areas, as well as connections to natural aquatic systems as they existed before land-use conversions, land leveling, and other human-induced modifications.

Ideally, hydrology should be restored by methods that require little, if any, long-term maintenance. Flashboard risers and other water control structures requiring occasional maintenance are acceptable if the area to be restored is under permanent management (e.g., a wildlife refuge) but will become problematic in projects that receive little postplanting attention. If long-term maintenance is required, it is likely that nature will eventually take over, and the area may not remain a wetland.

Wetland restoration projects that rely on pumped water, for example, are suspect because of the long-term maintenance and expense required.

Where hydrologic modifications are the result of larger scale drainage, it may not be feasible to restore the natural hydrology. Flood control projects on major rivers or channel modifications that have resulted in a dropping of the water table, for example, may put hydrologic restoration beyond the capability of the restorationist. It may still be possible to partially restore the hydrology with the realization that under some conditions, such as large-scale flood events, an unnatural hydrology may still dominate. In these situations, the best that can be done is to make sure the species planted are appropriate for the expected hydrology.

Whenever a modification of the existing hydrology of a field site is contemplated, every effort should be made to ensure that adjacent landowners will not be affected. Increasing the flooding on a field to be restored, for example, may also increase the flooding of adjacent fields that are still in crop production or possibly on roads or residential areas. Any modification to the local hydrology will likely have some effect outside of the project area. A reduction of flooding in one area almost always results in increased flooding somewhere else. The possibility of these unwanted effects should be investigated before project initiation.

Restoring Soil

Most old fields have at least a moderate degree of soil compaction, mainly because of repeated use of heavy farm equipment. Soil compaction can usually be easily overcome by disking (fig. 5.1). Ideally, fields should be disked no more than 2 months before planting. However, disking may need to be done earlier if mid- to late-winter planting is planned and if flooding is a possibility. Two passes with the disk plow or harrow should be made, and disking should be to a depth of at least 15 cm (6 inches) but preferably 20-35 cm (8-14 inches). Disking to these recommended depths may be difficult or impractical on some heavy clay sites, although it can sometimes be accomplished by waiting until soils are moist throughout the desired depth.

In cases where compaction is especially severe, the field should be subsoiled by using a chisel plow or ripper (fig. 5.2). Subsoiling is most effective when the soil is dry and should be done far enough in advance of planting to allow rainfall to close up and firm the soil. Normally, the soil should be ripped to a depth of 45-60 cm (18-24 inches). On most soils, the tractor should have at least 40 horsepower per shank, but more power may be required on heavy clays. Ripped furrows should be oriented with the landform contour in areas with potential for erosion. Where trees are to be planted in rows, spacing between furrows should correspond to the desired spacing.

Although the soils on most bottomland old-field sites are naturally fertile, their fertility has often been reduced over time by repeated cropping or poor management. In general, nitrogen is the most limiting nutrient, followed by phosphorus and potassium. If the early growth rate of the planted trees is critical, a soil test should be carried out before planting, and the field should be fertilized as needed.

Since fertilization may cause a lush growth of weedy species, it may be necessary to plan for some postplanting weed control if fertilization is planned. If no postplanting weed control is carried out, fertilization may indirectly reduce survival of planted trees by increasing the population of small rodents, which are attracted to the increased weed cover.

Control of Plant Competition

On old fields that have been fallow through one or more growing seasons, weed cover may need to be reduced or eliminated before planting. Eliminating weeds will reduce plant competition and temporarily reduce the number of small mammals that may destroy planted seeds or seedlings. A particularly effective way to do this is by disking because not only does it reduce soil compaction but it increases soil organic matter (by turning the weeds into the soil). A variety of other types of farm or construction machinery can also be used for weed control if necessary (e.g., bushhog, mowers, scrapers, bulldozers), but disking is generally preferable.

Prescribed fire is another tool that can be used to reduce weed cover effectively. Late spring burns, for example, are generally very effective in reducing the cover of highly competitive pasture grasses such as fescue. Fire does, however, have some potentially serious disadvantages. There is always the danger of the fire escaping and causing damage to nearby property, smoke can reduce visibility on adjacent roads, and the time when burning can be done effectively (and safely) is relatively limited. Prescribed fire for weed control should be carried out only by trained personnel with adequate fire control equipment. Also, permits to conduct prescribed burns are required in some areas.

Herbicides are frequently used for weed control in commercial forestry applications but are not recommended for site preparation on old fields except as a last resort. Examples of situations where use of herbicides may be justified include sites where weed cover is too heavy to use a disk, where use of heavier equipment or prescribed fire is not feasible, and on sites with a

Figure 5.1. Old field being disked to alleviate soil compaction before planting. Disking can also be used to create a fire break around a restoration site.

Figure 5.2. Subsoiling for severe cases of soil compaction.

significant cover of exotic or particularly noxious native weed species.

Site Preparation on Heavily Disturbed Sites

Surface-mining and other activities that drastically alter a site have caused much less loss of bottomland hardwood forests than clearing for agriculture. Coal mining, however, has affected some bottomland hardwood areas, most notably in the lower Midwest, and phosphate mining has caused extensive losses in Florida and smaller losses in North Carolina and Tennessee. Peat mining has damaged pocosins in the Carolinas, and localized sand and gravel mining has affected sites throughout the lower Midwest and southeastern United States.

While the losses of forested wetlands due to mines are relatively small, areas affected are much more dramatically altered than agricultural fields (fig. 5.3). Restoration of these sites is costly and complex and should be attempted only by experienced restorationists working closely with mine managers and reclamation engineers.

Throughout this discussion about site preparation on heavily disturbed sites, the term "restoration" is used. The terms "created" or "constructed," however, are often more appropriate for such discussions because an entire ecosystem must be established, including soils, hydrology, and biotic communities. Also, the newly established ecosystems may either be the same types of ecosystems originally on the project site but in different locations than the original systems, or they may be entirely new types of ecosystems.

Surface Contouring

The first consideration for site preparation on heavily disturbed sites is to establish an appropriate surface contour. Because the landscape has been so drastically altered, the restorationist first needs to decide what kind of ecosystems are to be created on the reclaimed land, how they should be placed in relation to each other, and how they should interact with existing ecosystems on adjacent unmined lands. The guiding principle is to integrate the new contour into the regional drainage system.

A restored bottomland forest should function ecologically within the regional drainage system in a manner comparable to bottomland forests on undisturbed lands. Therefore, the restored forest must be positioned where

Figure 5.3. Phosphate mine site showing the degree of habitat alteration.

it receives adequate surface runoff and groundwater baseflow to maintain a desirable hydroperiod. Prediction of the hydrologic regime that will occur after contouring is probably the most technically difficult challenge involved in restoration. Such predictions require that surface and groundwater flows be determined, with full consideration given to seasonal hydrologic patterns and expected flows during extreme events (such as 100-yr storms and unusually dry periods). Ideally, the restorationist should work closely with a hydrologist when designing the surface contour for a project site.

The restorationist should know the types of materials that are available for use as fill for the site and how they will influence hydroperiod, surface and subsurface flow, groundwater quality, and soil development. Clayey materials, for example, may swell upon hydration, possibly affecting water table depths and zones of soil saturation. In other cases, much of the fill material might be nearly pure sand, which will cause entirely different groundwater dynamics and tree survival.

The construction of a stream channel poses special challenges. Extensive gullying and downstream sedimentation can happen during a single heavy rainstorm, requiring difficult repairs and disrupting other project activities. Stream channels are less prone to gullying if they are relatively broad, shallow, and have a gently rounded bottom configuration. They should also have a low gradient and be meandering, rather than straight, because this will act to retard erosive flows in storm events. The bottom should either consist of indurated materials or should be vegetated with densely rooted wetland plants. Grading techniques, soil treatments, and cover crops that encourage the rapid infiltration of surface runoff upslope will also diminish the potential for channel erosion.

It is difficult to create a natural-appearing yet completely stable channel, so it is likely that the shape of the channel will change somewhat over time. Natural stream channels also change over time, thus some change in the course of the created stream channel should be expected, tolerated, and even planned. One way to introduce a dynamic element is to place barriers made of logs at intervals along the created channel. The logs will help reduce stream velocities and initiate meandering. Logs are present in natural streams, and in addition to affecting stream morphology, play a major role in the stream ecosystem by acting as a substrate for invertebrate and algal production and as a site for feeding by fish and wading birds.

Restoring Soil Characteristics

Restoring soils on heavily disturbed sites is a much more difficult and expensive proposition than it is on old fields. Among other things, the soils on heavily disturbed sites may have the original soil horizons mixed together, may be more (or less) acidic, may be highly compacted, and typically have much less organic matter.

Where possible, the impacts of projects that drastically alter soils can be minimized by stockpiling the topsoil (organic material and surface mineral horizons) separately from the underlying horizons. Once the surface is contoured, the topsoil can be placed back on the surface.

The postproject soil conditions will not be identical to preproject conditions, of course, but stockpiled topsoil is still generally preferable to a more thoroughly mixed soil. An exception is heavy clay topsoil, which may impede infiltration of water when spread over mined and reclaimed land. Also, it should be recognized that many bottomland soils are Inceptisols or Entisols (soils with relatively little profile development). This makes identification of topsoil rather difficult, but it is generally safer to mix surface and subsurface soil horizons of young soils than it is to mix more developed soils.

When using stockpiled topsoil, every effort should be made to minimize the time that soil is stored because organic matter and numbers of desirable soil organisms usually decline rapidly. Also, stockpiles should be kept as low as possible because the quality of stockpiled topsoil declines substantially when the depth exceeds 1 m.

The surface soil of a recontoured site will often be nearly devoid of organic matter. Cover crops and volunteering weeds contribute humus, but additional organic matter will accelerate forest establishment and soil maturation. If possible, organic matter should be added to the surface soil at the conclusion of final grading. Composted sludge has shown promise in experimental plots as a source of both organic matter and nutrients. Yard trimmings, which municipalities may provide without charge, are another source of organic matter. Experimental plantings conducted by the Florida Institute of Phosphate Research have shown that hay cover significantly increases tree survival and growth. Hay, if applied in a deep enough layer, conserves soil moisture, prevents the establishment of competitive weeds, retards erosion, and reduces the daily changes of soil temperatures in the root zone. If applied in a thin layer that allows sunlight through to the soil surface, though, seeds carried in the hay can foster pernicious growth of weeds and turf grasses. Pine straw (needles) have also been used effectively as a mulch.

Establishment of Ground Cover

In an effort to reduce soil erosion, many regulatory agencies require that surface mined and other highly disturbed sites be planted with a cover of grass immediately after surface contouring. Usually, a rapidly growing and spreading species such as fescue, Bahia grass, or Bermuda grass is required. Unfortunately, the same characteristics that make these ground cover species good for erosion control make them strong competitors with planted tree seeds or seedlings. Tree survival and growth are almost always diminished when the planting site is covered by these species.

While planting a ground cover species may reduce erosion in some cases, the nearly flat soil surface typical of forested wetland restoration sites and the rapid natural invasion of herbaceous species on these sites already reduce the potential for erosion. Such plantings, which are sometimes required in mitigation plans, are therefore of questionable value on wetland sites.

An alternative to planting aggressive grass species is to plant nitrogen-fixing species (such as clovers, alfalfas, or many other legumes) that can be disked under after one growing season as green manure. Green manuring can reduce erosion and at the same time improve soil structure and fertility. The main drawback to this practice, however, is that the desired tree species cannot be planted during the first growing season after contouring.

Selected References

Allen, J.A., McCoy, J., and Keeland, B.D., 1998, Natural establishment of woody species on abandoned agricultural fields in the Lower Mississippi Valley: first- and second-year results, *in* Waldrop, T.A., ed., Proceedings of the Ninth Biannual Southern Silvicultural Research Conference, February 25-27, 1997, Clemson, S.C.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-20, p. 263-268.

Clewell, A.F., and Lea, R., 1990, Creation and restoration of forested wetland vegetation in the southeastern United States, *in* Kusler, J.A., and Kentula, M.E., eds., Wetland creation and restoration, the status of the science: Washington, D.C., Island Press, p. 195-231.

Dennington, R.W., 1989, Ripping can improve tree planting success: Atlanta, Ga., U.S. Department of Agriculture, Forest Service, Southern Region, Management Bulletin R8-MB 31, 2 p.

Federal Interagency Stream Corridor Restoration Working Group, 1998, Stream corridor restoration: principles, processes, and practices, National Engineering Handbook (NEH), Part 653: Washington, D.C., U.S. Department of Agriculture, Natural Resources Conservation Service.

Hutchison, M., 1992, Vegetation management guideline: fescue (*Festuca pratensis* Huds.): Natural Areas Journal, v. 12, no. 3, p. 157-158.

Myles, D.V., 1978, A compendium of silvicultural equipment, Forest Management Institute Information Report FMR-X-115: Ottawa, Canadian Forestry Service, Environment, Canada.

Rathfon, R.A., Kaczmarek, D.J., and Pope, P.E., 1995, Site preparation for red oak plantation establishment on old field sites in southern Indiana, *in* Gottschalk, K.W., and Fosbroke, S.L.C., eds., Proceedings of the 10th Central Hardwood Forest Conference: Radnor, Penn., U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, General Technical Report NE-197, p. 349-362.

Chapter 6: Seed Collection, Handling, and Storage

Quality seed must be obtained regardless of whether the method of reforestation will be direct seeding or by planting seedlings. It is assumed for the purposes of this guide that the restorationist is not planning to grow his or her own seedlings; rather, it is expected that the seed will either be sown directly on the site to be restored or given to a nursery for seedling production. Guides to the production of seedlings in nurseries are provided in the references at the end of this chapter, but nursery management is too large in scope to be covered in this guide.

Seed Collection

Regardless of the type of seed to be collected, five principles will always apply. First, the restorationist must know when the seed of the species of concern ripens (see table 4.1) and should scout the seed crop as it nears maturity. If adequate storage facilities are available, it is advisable to take full advantage of years with good seed production because collection is easier, usually more of the seed is viable, and it ensures an adequate supply of seed during years with poor seed crops.

Second, collection should take place as soon as the seeds are mature. If seeds are collected too early they may not germinate, or high moisture content may lead to handling and storage problems. If collection begins too late, much of the crop may have been eaten or otherwise made inviable.

Seed maturity is often indicated by color. For instance, the fruits of ashes, sweetgum, yellow poplar, and sycamore all should have turned from green to greenish-yellow or yellow by the time they are collected. Maturity of acorns can be recognized by the color of the nut (pericarp), which is green when immature, brown or black for mature acorns in the red oak group (e.g., cherrybark oak, laurel oak, Nuttall oak, pin oak, Shumard oak, water oak, and willow oak), and brown or a mottled-looking, yellow-brown for mature acorns in the white oak group (e.g., bur oak, Delta post oak, live oak, overcup oak, swamp chesnut oak, white oak, and swamp white oak). Another good criterion for acorn maturity is easy release from the cups; immature acorns are more difficult to separate from their cups.

Third, if possible, seeds should be collected from trees in the same general area as the site to be restored. The abiotic factors of the site where the seeds are collected (see Chapter 3) should resemble those of the restoration site as closely as possible to help insure that the seedlings will be adapted to the local environment.

Fourth, to enhance genetic diversity, seeds should be collected from numerous trees, preferably at least ten. To help maximize genetic diversity, seed trees should be at least 100 m apart. If timber production is an objective, collection should be from mature trees of good form, even though this may make collection more difficult. Likewise, if production for wildlife is the main objective, collection should be from the heaviest seedbearers.

Fifth, records should be kept on each batch of seed collected and include at a minimum the species, the date, and the specific location (provenance) of collection. Subsequent seedling performance for each lot can then be checked, and the best seed sources can be used in future restoration projects.

Most collection of bottomland hardwood seed is done in forests rather than in seed orchards. Seeds are typically collected manually, either by collecting freshly fallen seed from the ground, by using pruning poles, by climbing trees, or by collecting from logging slash (fig. 6.1). When possible, it is worth taking advantage of logging operations, because seed collection directly from felled trees can be easy, and many other seeds will fall on the ground during felling. Mechanized seed collection techniques exist (see references at the end of this chapter).

Inevitably, nonviable seed will be collected along with viable seed, but this can be minimized by learning to recognize indicators of seed quality. If there is evidence of insect depredation, decay, or physical damage, or if the seed feels exceptionally light, it should be discarded. Cutting open a small number of seeds to look for signs of insect infestation, decay, or other problems is advisable.

In the field, freshly collected seed should NOT be kept in plastic or other containers providing low aeration (fig. 6.1), especially if large batches of seed are being collected at one time and it will be a day or more before the seed is processed. The combination of heat buildup due to cellular respiration and the high moisture content of fresh seed can damage seed and promote the growth of molds.

Seed Handling

Seed handling steps include seed extraction and drying, separation of chaff and nonviable seed from sound seed, and in some cases, prestorage treatments. Depending on the type of seed and the type of planting operation planned, not all of these steps may be necessary.

Most seeds, other than heavy-seeded species such as oaks and hickories, require some type of drying and/or extraction process. The first step is usually air-drying. Screens or trays can be set up outdoors (and protected

Figure 6.1. Fresh acorns being collected in an appropriate container in the field.

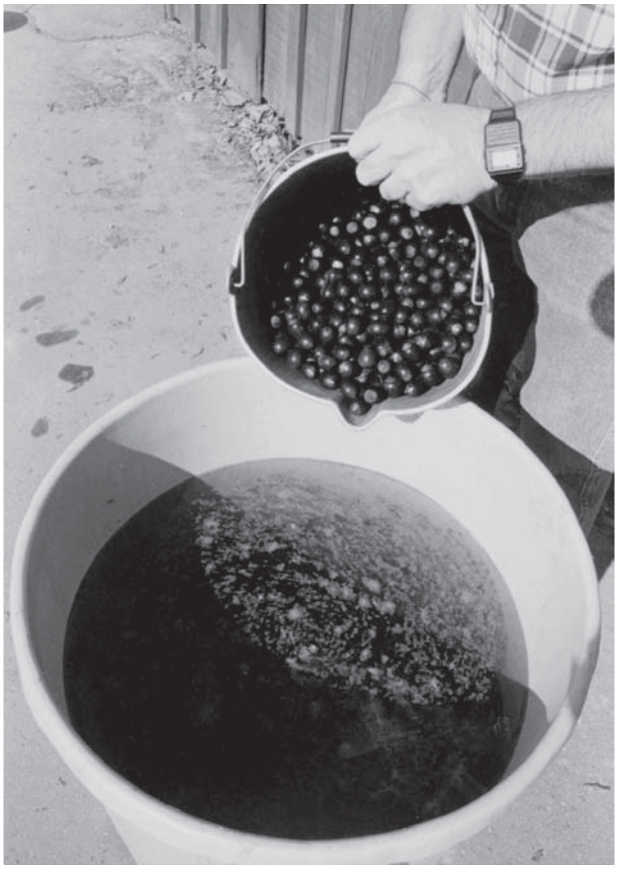


Figure 6.2. Processing acorns using the float test to determine viability. Nonviable acorns float to the top and are discarded.

from rain, dew, and excessive direct sunlight) in a greenhouse or in a building. Fruits and cones should be air-dried only until the point where extraction is possible (e.g., the cones or pods open up); longer drying may reduce viability. Solar driers, kilns, and other mechanized means of drying are recommended when large batches of seed will be handled annually.

Seeds within fleshy coverings should be extracted before drying to avoid fermentation or spoilage. The fleshy material can be removed first by macerating the fruit by hand (perhaps by rubbing the fruits across hardware cloth) or with a machine such as a feed grinder or commercial seed macerator and separator. The seed of some small stony-seed species (e.g., the hollies) can be extracted using an ordinary blender with a little water added. Following maceration of the fruits, seed can be separated from the fleshy material and other debris by swirling in a bucket of water. Once the seed is completely separated, it will sink if viable.

Because viable acorns of most oak species sink in water, a float test is highly recommended (fig. 6.2). The float test will work for all oak species except overcup oak, which floats when viable because it retains its cup after the acorns are mature. In addition to separating viable acorns from unsound acorns and other chaff, the float test can also serve to rehydrate desiccated acorns.

Acorns should be floated on the day of collection but can be placed in cold storage for several days before floating if necessary. If conditions are dry at the time of collection, acorns should be left in the water for 16-24 h because many viable acorns will float at first if a little dry. The acorns should be stirred once or twice to allow all unsound acorns to float up to the surface. After flotation, the unsound acorns and chaff should be skimmed off the surface and the water drained away. Complete surface drying of the acorns is not necessary, but there should not be enough water remaining to form a pool in the bottom of the container.

Seed Storage

Seeds of many species can be stored for several years (at least five) if dried to a moisture content of 6-10%, placed in airtight containers, and kept at temperatures slightly below freezing (-18 to -1 °C [0-30 °F]). Storage for shorter periods can often be successful at normal refrigerator operating temperatures of around 2-3 °C (36-37 °F) (table 4.1).

Acorns, however, are a special case. Even with the best of care, acorns of white oaks generally cannot be stored longer than a few months, and the percentage of viable red oak acorns drops substantially after 3 years. Following guidelines provided by the U.S. Forest Service's Southern Hardwoods Laboratory (Johnson, 1979; Bonner and Vozzo, 1985), the Louisiana Department of Wildlife and Fisheries has been able to store overcup oak acorns for up to 2 years and Nuttall oak acorns for up to 6 years (Larry Savage, Louisiana State Department of Wildlife and Fisheries, personal communication).

To store acorns successfully, high moisture content must be maintained: about 35% for red oaks and 50% for white oaks (wet weight; see table 4.1). High moisture content is best accomplished by placing the acorns in storage immediately after completing the float test (fig. 6.3). Occasional testing of moisture content is recommended during storage. If the moisture content drops below 30% for red oaks or 40% for white oaks, the acorns should be immersed in water for at least half a day. Actual measurements are not always required; when acorns are stored in clear plastic, condensed moisture on inside bag walls indicates that acorns are still moist.

Figure 6.3. Sacks of acorns in a large cold storage unit.

It is important to keep acorns cool but at temperatures above freezing (1-3 °C [34-37 °F]). Bags or other containers used to store acorns should not be completely airtight but should be loosely fastened. Containers should be separated within the cold storage unit to allow for air circulation. If bags are used, they should be placed on wire racks rather than on solid shelves (fig. 6.3). Turning the bags frequently is also recommended. Polyethylene bags 0.1-0.15 mm (4-6 mils) thick holding up to about 11 kg of acorns work very well because they hold in moisture but allow exchange of oxygen and carbon dioxide, which is necessary because cellular respiration still occurs. Drums or boxes with polyethylene liners are also satisfactory. There is some evidence that because white oak acorns tend to respire more rapidly than red oak acorns, they may store better in cloth bags or polyethylene bags (or liners) as thin as 0.04 mm (1.5 mils) thick. If facilities for refrigeration are not available, acorns can be stored successfully over a winter by burying them 30-60 cm (12-24 inches) underground.

Nuttall oak acorns have also been stored successfully over one winter in refrigerated tap water and wet sand. Storage in water apparently also reduces the number of acorns that germinate in storage.

A 4-8 week period of cold stratification is recommended for most southern oaks. A somewhat longer period (8-12 weeks) is recommended for Shumard oak and water oak. In general, the needs for stratification are met by proper cold storage.

Selected References

Aldhous, J.R., and Mason, W.L., 1994, Forest nursery practice: London, United Kingdom, Forestry Commission Bulletin, No. 111, 268 p.

Bonner, F.T., 1986, Good seed quality—how to obtain and keep it, *in* Proceedings of the Northeastern Area Nurseryman's Conference, July 14-17, State College, Penn., p. 31-36.

Bonner, F.T., 1992, Hardwood seed, *in* Branan, J., and Morrhead, D., eds., Proceedings of the Southern Forest Nursery Association Conference, July 20-23, Pine Mountain, Ga.: Georgia Forestry Commission and Southern Forest Nursery Association, p. 67-90.

Bonner, F.T., 1993, Collection and care of acorns, *in* Loftis, D.L., and McGee, C.E., eds., Oak regeneration: serious problems, practical recommendations, Oak Regeneration Symposium, September 8-10, 1992, Knoxville, Tenn.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-84, p. 290-297.

Bonner, F.T., and Vozzo, J.A., 1985, Seed biology and technology of *Quercus*: New Orleans, La., U.S. Forest Service, Southern Forest Experiment Station, General Technical Report SO-66, 21 p.

Bribbo, L.S., and Jones, W.E., 1995, Test of the float method of assessing northern red oak acorn condition: Tree Planters' Notes, v. 46, no. 3, p. 143-147.

Johnson, R.L., 1979, A new method of storing Nuttall oak acorns over winter: Tree Planters' Notes, v. 30, no. 2, p. 6-8.

Liegel, L.H., and Venator, C.R., 1987, A technical guide for forest nursery management in the Caribbean and Latin America: New Orleans, La., U.S. Forest Service, Southern Forest Experiment Station General Technical Report SO-67, 156 p. [Though not intended for the area covered in this report, this guide contains much useful information on seed handling and seedling production.]

Nisley, R.G., 1995, The container tree nursery manual, Volumes 1-5: U.S. Department of Agriculture, Forest Service, Agriculture Handbook 674.

Rink, G., and Williams, R.D., 1984, Storage technique affects white oak acorn viability: Tree Planters' Notes, v. 35, no. 1, p. 3-5.

Suszka, B., Muller, C., and Bonnet-Masimbert, M., 1996, Seeds of forest broadleaves: from harvest to sowing: Paris, France, Institut National de la Recherche Agronomique.

William, R.D., and Hanks, S.H., 1994, Hardwood nursery guide: U.S. Department of Agriculture, Forest Service, Agriculture Handbook No. 473, 78 p.

Young, J.A., and Young, C.G., 1992, Seeds of woody plants in North America: Portland, Ore., Dioscorides Press, 407 p.

Chapter 7: Direct Seeding

Direct seeding is an important bottomland hardwood forest restoration technique, particularly for establishing oaks on old-field sites and sites surface-mined for coal. In situations where it can be applied successfully, direct seeding is very appealing because it is relatively inexpensive compared with planting tree seedlings (table 7.1). Direct seeding may cost as little as half of what planting seedlings costs on a per area basis, although the cost depends on factors such as the price of seed and labor, the availability of suitable equipment, and the success of the first direct seeding effort.

Direct seeding is also appealing because of its flexibility. The planting window for direct seeding is much longer than for planting seedlings (see the seasonal timing section, this chapter, and Chapter 8); therefore there is greater freedom in scheduling site preparation and planting operations.

Another advantage of direct seeding is that it allows the tree's roots to develop naturally. In contrast, seedlings taken from a nursery or the wild usually have had their roots pruned, balled up, or twisted. Also, it is very difficult to plant a seedling so that its roots are as spread out as they would be naturally, even if seedlings arrived from the nursery in perfect condition. To do so requires digging a wider planting hole and taking much more care placing soil around the roots than is typically done. This extra attention to planting slows the planting operation and ultimately costs more money. Roots that develop unnaturally may cause the tree to be more susceptible to drought stress and windthrow.

On the other hand, many direct seeding projects have failed, sometimes because newly germinated seedlings lack sufficient energy reserves to survive stresses caused by events such as dry periods. It is likely, however, that most failures have been caused by lack of attention to one of eight controllable factors described by Toumey and Korstian (1942): (1) seed quality; (2) species selection; (3) competing vegetation present on planting site; (4) soil condition; (5) presence of seed predators; (6) seeding rate; (7) timing of seeding; and (8) depth of sowing. The Louisiana Department of Wildlife and Fisheries suggests that proper handling of seeds from cold storage to actual planting be explicitly considered in item (1) above because seed quality can diminish very rapidly if the seed is not protected from heat and sun before planting.

Recent successes, such as those obtained by Louisiana Department of Wildlife and Fisheries personnel in northern Louisiana (fig. 7.1), demonstrate that direct seeding can be effective. In addition, recent evidence suggests that some sites planted by direct seeding of acorns that were considered failures were later determined to meet density requirements. The lack of apparent early success may have been a result of delayed germination, rodents clipping the stem (but not killing the roots), or the difficulty of locating small seedlings in dense herbaceous vegetation. Most practitioners recommend that sites planted by direct seeding should not be abandoned until they have been evaluated at least 5 years after planting.

A major limitation of direct seeding as currently practiced is that its use is restricted mostly to oaks and other large-seeded species. The few efforts that have been made with light-seeded species (such as ashes, sweetgum, and elms) have almost all failed, although some successes with green ash have been reported in West Virginia and eastern Kentucky. The failures were primarily due to depredation by birds and rodents or to drought stress shortly after germination. Because small-seeded species have low energy and moisture reserves they are particularly susceptible to drought. It is probable that these light-seeded species, which must be sown on or near the soil surface, will require some sort of protection in order to become established. Use of rodent and bird repellents may eventually prove successful, but none have been demonstrated to work on bottomland hardwood species at this time. Mulches, slurries, and other techniques may also work, but no evidence exists that these have been tried in bottomland projects. Limited trials in Florida suggest that direct seeding of light-seeded species requires exposed, moist mineral soil and regularly distributed rainfall for several months after seeding.

Seasonal Timing

Most direct seeding is done in late fall, spring, or early summer. Research with red oak acorns indicates that direct seeding may also be successful at all other times of the year; however, Wood (1998) showed that cumulative germination of Nuttall and willow oaks was greatest with December planting (~70%), less with March planting (~50%), and least with June planting (~15%). The period of June through October is not recommended in most of the Deep South.

Species such as the white oaks, which are difficult to store successfully, are most likely to do well when planted immediately after seed collection (i.e., in late fall). Other types of seed can be stored and planted when labor and equipment are not engaged in other activities or when planting conditions on the site are most favorable for the type of equipment being used. At least some red oaks (Nuttall and willow) perform best when planted in December, regardless of flood conditions (Wood, 1998).

Table 7.1. Pros and cons of direct seeding and planting seedlings (from Haynes and others, 1995).

Pros	Cons
Direct Seeding	
Typically about half to one-third as expensive as planting seedlings.	Proven reliable only for oaks and some other large seeded species.
Roots develop naturally without problems caused by disturbing roots and removing seedlings from nursery.	Slower initial establishment and development, although long-term growth and survival may not be significantly different from seedlings.
Acorns may remain in a dormant state for a period of time under adverse site conditions (drought or too wet), thereby increasing survival potential.	Local acorn supply for one or more species may be scarce or difficult to obtain from commercial sources.
Can plant twice as fast, normally using a two-row planter versus a one-row with a seedling planter (however, there are some two-row seedling planters now being used).	Rodents can sometimes be a problem by digging up and eating the acorns; however, planting in large open fields typically results in little damage.
Proven method of reforestation when site is properly prepared using viable seed that has been properly stored.	Cold storage of acorns is generally limited to red oaks (see table 4) and sweet pecan. White oaks do not usually store well for periods greater than 3 months.
Window for planting is longer than for seedlings (acorns can usually be planted successfully from October through April or May).	Acorn-adapted planters (i.e., J.D. Max-Emerge 7100, converted) have more working parts, thus more potential for breakdowns than seedling planters.
	More difficult to monitor success, since it takes several years for germinated seedlings to become large enough to find easily.
Planting Seedlings	
Planting tree seedlings is a reliable and well established method of reforestation.	About two or three times as expensive as direct seedling of acorns.
Usually a good selection of reliable commercial suppliers of seedlings; seedlings available for many species.	Seedlings subjected to adverse site conditions (drought or severe flooding) will perish quickly.
Initial seedling development is faster than for planting acorns, although long-term growth and survival may not be significantly different.	Seedlings must be planted during the dormant period (January through March) when many bottomland forest sites may be flooded. Planting in extreme wet conditions must be done by hand.
Taller seedlings may be able to survive flooding events during the growing season if water does not top the seedling for extended periods.	Seedlings that have been fertilized in the nursery are a preferred food for rodents and deer.
For monitoring compliance and determination of planting success, planted seedlings are easier to locate than newly germinated seedlings from acorns or other seed.	

Depth of Sowing and Spacing

Acorns and other large seeds can be sown successfully at depths between 5-15 cm (2-6 inches). Sowing 5-10 cm (2-4 inches) deep usually results in better germination and survival than sowing between 10-15 cm (4-6 inches), and is easier (and faster) than sowing deeper. Wood (1998) observed significantly greater germination for seeds sowed at 7-10 cm (3-4 inches) than sowed at 3-5 cm (1-2 inches) in the absence of herbivory. Sowing deeper than 10 cm (4 inches) may pay off, however, in situations where there are a lot of rodents or the soil surface is subject to freezing or drying out completely.

Experience has shown that as many as 25% of acorns sown in relatively weed-free old fields, and about 10% of acorns sown in cleared forests, will produce trees still growing well after 10 years. Initial germination and establishment success may be as high as 80%, but usually it is closer to 35 or 40%. Based on these initial germination and longer term survival estimates, sowing of acorns should range from 1,700-3,700 acorns per ha (700-1,500 per acre). On old fields with good site preparation, 1,700-2,500 acorns per ha (700-1,000 per acre)

Figure 7.1. Restoration site where oaks have been successfully established by direct seeding (Ouachita Wildlife Management Area, Louisiana).

should be adequate. Sowing rates of 3,000-3,700 acorns per ha (1,200-1,500 per acre) are recommended for sites where seedling survival is questionable, including mine spoils and areas with a dense vegetative cover. Savage et al. (1996) reported that seeding rates of 5,900 acorns per ha (2,400 per acre) were necessary in a field with a particularly high population of rice and cotton rats. Because acorns are a relatively inexpensive part of the overall direct seedling operation, higher seeding rates should be seriously considered where appropriate.

Direct seeding is generally done in rows, which are most often spaced between 2.5-4.5 m (8-15 ft) apart. Spacing within rows will depend on the distance between rows and the number of seeds sown per acre; a range of possible spacings is depicted in table 7.2. If the aesthetics of the reforested site are an important consideration, the restorationist can avoid the appearance of a plantation, with its neat rows of trees, by planting in wavy lines or even at random. The main thing to keep in mind is to allow adequate growing space around each seed.

Table 7.2. Number of seed or seedlings required per hectare (acre) at various spacings.[1]

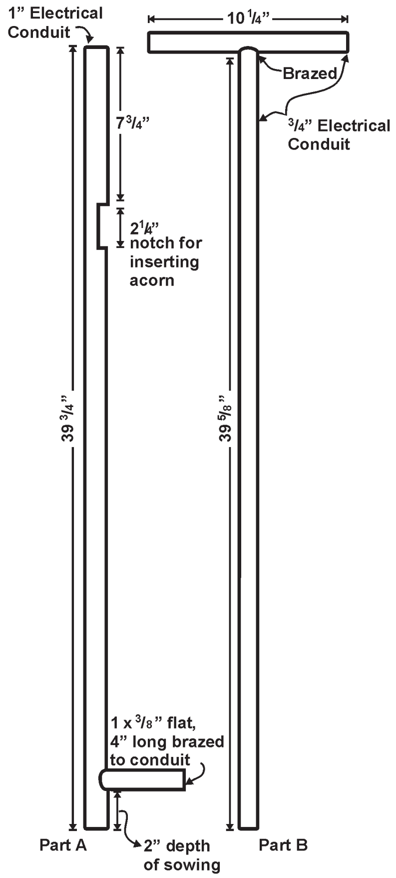
Spacing		Number	
Meters	**Feet**	**per ha**	**(acre)**
0.75 × 3.65	2.5 × 12	3,586	(1,452)
0.9 × 1.80	3 × 6	5,977	(2,420)
0.9 × 2.75	3 × 9	3,984	(1,613)
0.9 × 3.65	3 × 12	2,989	(1,210)
0.9 × 4.57	3 × 15	2,391	(968)
1.8 × 1.80	6 × 6	2,989	(1,210)
1.8 × 2.75	6 × 9	1,993	(807)
1.8 × 3.65	6 × 12	1,494	(605)
1.8 × 4.57	6 × 15	1,195	(484)
2.44 × 3.05	8 × 10	1,346	(545)
2.75 × 2.75	9 × 9	1,331	(539)
2.75 × 3.65	9 × 12	995	(403)
2.75 × 4.57	9 × 15	798	(323)
3.05 × 3.05	10 × 10	1,077	(436)
3.05 × 3.65	10 × 12	897	(363)
3.65 × 3.65	12 × 12	746	(302)
3.65 × 4.57	12 × 15	598	(242)
3.65 × 6.10	12 × 20	450	(182)
4.57 × 4.57	15 × 15	479	(194)
4.57 × 6.10	15 × 20	358	(145)
6.10 × 6.10	20 × 20	269	(109)

[1] Assuming a 25% survival rate for direct seeding of acorns, reduce number per area by 75% to estimate the number of surviving trees per area (ha or acre) (Haynes and others, 1995).

Hand Sowing

Direct seeding by hand can be accomplished using very simple and inexpensive equipment. The simplest approach is to use a metal bar, broomstick, or even a stick found in the woods, to make a planting hole. The seed is then dropped in the hole, after which the planter closes the hole with his or her foot. A hand tool, such as the one developed by the U.S. Forest Service (fig. 7.2), can make the job easier because the seed is dropped down the tube to a preset depth in the ground, thereby avoiding the need to bend over to put the seed in the hole. The hole is then closed by foot.

On a relatively clean site with favorable soil moisture conditions, a single planter with the Forest Service's hand planter can sow 2.8-3.2 ha (7-8 acres) per day at a rate of 3,000-3,700 seeds per ha (1,200-1,500 per acre). A planter using just a stick or bar probably will plant no more than 2.0-2.5 ha (5-6 acres) per day. These rates can decline considerably depending upon the experience and physical condition of the planter, the depth of sowing, the distance the planter has to hand carry seed before being able to start planting, and the actual site conditions.



To assemble:
insert Part B into Part A.

Figure 7.2. This hand tool, developed by the U.S. Forest Service, can make hand sowing of acorns much easier.

Machine Sowing

On clean sites with slopes of 10% or less, sowing seeds with a mechanical planter may work very well. Almost all of the planters that have been used on bottomland hardwood sites in the past are modified agricultural planters.

Two main types of modifications to agricultural planters have been made to date. One modification involves placing seats behind the drop tubes and requires personnel to ride on the planter and drop seeds in by hand (fig. 7.3a). The second modification involves adapting a no-till planter so that it can handle both the deeper planting depths and larger seeds that are necessary when direct seeding acorns, while still dropping the seeds automatically (fig. 7.3b). Specifically, use of agricultural (no-till) planters requires modification of the hopper bottoms and drop tubes to handle acorns (especially the larger species, such as Nuttall oak) and installation of heavy-duty coulters, down pressure springs, closing wheels, and other equipment that allows the planter to dig deep enough into the soil, cut through a heavy weed cover, and drop in large seeds.

Although not essential, an electronic seed monitor is desirable when using modified no-till planters. Seed monitors let the tractor operator know if the hoppers become jammed and seeds are not being planted properly, which is a frequently encountered problem. Jammed hoppers are common because tree seeds tend to be more irregular in size, and more foreign matter is likely to be present than in agricultural seed lots.

Electronic seed monitors are expensive, yet they can be very cost effective. They eliminate the need for constant checking of the hoppers (and replanting rows that were “planted” with a jammed hopper). They can also reduce the size of the planting crew needed, since one person can both drive the tractor and continually ensure that seed is actually being planted.

Use of modified agricultural seed planters can greatly increase the rate of planting. Three people can sow at least 16-24 ha (40-60 acres) per day with the first type of modified planter, and one person can sow up to 8 ha (20 acres) per hour with the second type of planter equipped with a seed monitor.

At least two recently developed planters designed specifically for acorns or other large, irregular seeds appear to have real potential: the Truax large seed planter (fig. 7.4), and a planter designed by the U.S. Forest Service’s Missoula Technology and Development Center for sowing multiple rows of acorns in nursery seedbeds (fig. 7.5a,b). The basic design of the U.S. Forest Service planter (fig. 7.5a,b) could probably be adapted for use on restoration sites.

To date, very little direct seeding has been done using broadcast seeders, but this would appear to be quite possible and may become a viable method when there is a desire to avoid the look of a tree farm (i.e., with the trees in neat rows). One trial on the Ouachita Wildlife Management Area in Louisiana showed that the technique is feasible, but another trial showed that the method is less efficient than direct seeding by hand or machine, mostly because of rodent damage (Tom Dean, Louisiana State University, School of Forestry, Wildlife, and Fisheries, unpub. data). A few attempts at broadcast seeding have been made in Florida, but most have resulted in failure. The few successes were on freshly disked sites. More research and development work is needed before any specific guidelines on this approach can be published.

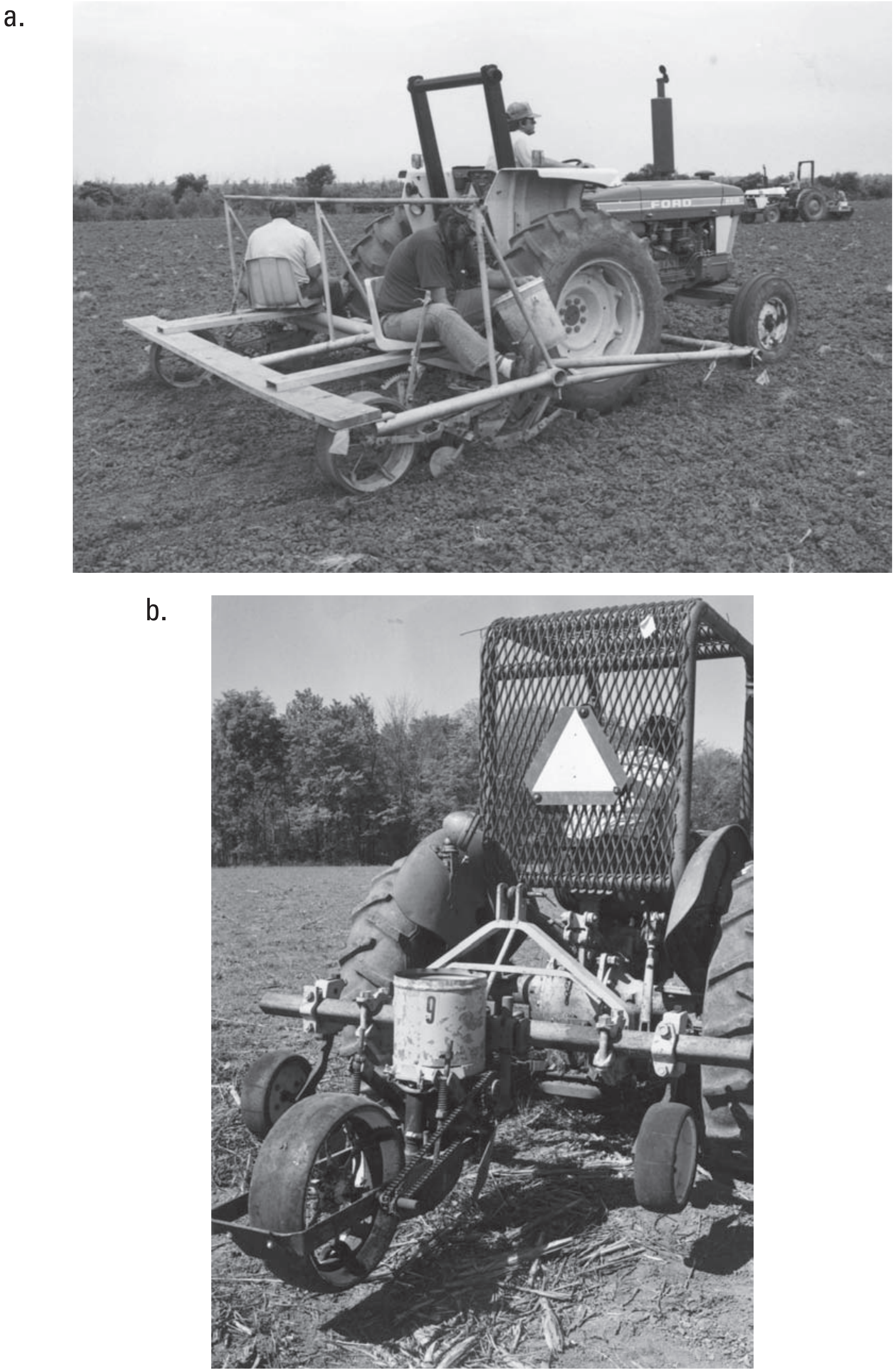


Figure 7.3. Two types of modified agricultural planters used for direct seeding: (a) planter requiring personnel to drop seeds in manually and (b) planter that drops seeds in automatically.

Figure 7.4. The Truax large seed planter.

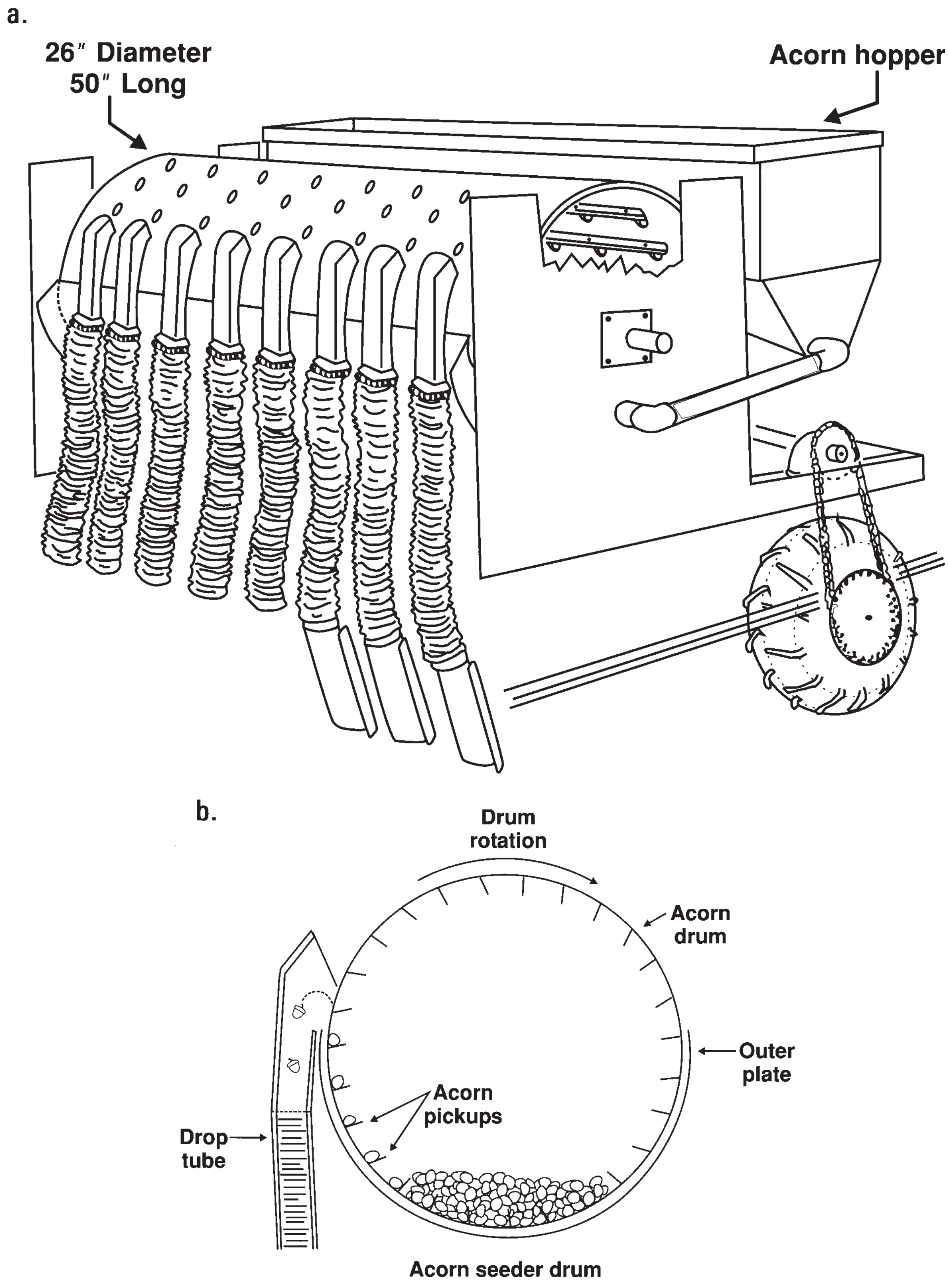


Figure 7.5. Machine developed by U.S. Forest Service for sowing acorns in nursery seedbeds: (a) machine sowing acorns and (b) schematic drawing of hopper mechanism.

Aerial Seeding

Aerial seeding has been widely used in the southern United States to sow pine seed, but it has rarely been used for direct seeding of hardwood species. The primary advantages of aerial seeding are that seeding rates are increased dramatically over manual and mechanical seeding; it can be more cost effective on large projects; it can be employed on sites too wet or unstable for mechanical seeders; and, because it is much faster than machine planting, more area can be planted during the sometimes brief window of suitable site conditions that exist on heavy clay soils. Also, in much of the area covered by this guide, aircraft normally used for crop dusting can be hired for direct seeding. Crop dusters often are not busy at the time of year direct seeding is carried out and may welcome the additional business.

Several small trials carried out between 1989 and 1992 in southern Arkansas, and more recently in the Mississippi delta by U.S. Fish and Wildlife Service, Division of Refuges (Larry Threet, Felsenthal National Wildlife Refuge, oral commun.), have shown that aerial seeding has potential on bottomland sites. In these trials, fields were disked in the fall prior to seeding so that large clods were produced. Then, a crop duster was loaded with acorns (fig. 7.6), and the seeds were broadcast over the field either in the fall or the following spring.

Several methods of burying the seeds after aerial seeding have been tried by the various refuge staffs. The simplest method was aerial seeding immediately before predicted rains with the hope that acorns would be buried as soil clods were broken up by raindrops. In other cases, the soil surface was rebroken in the spring just before seeding using a cutting disk or a field cultivator. All fields in the latter trial were also disked or cultivated after seeding, and some of the area was compacted using a roller drum.

These trials, although promising, showed that several aspects of the process need to be resolved before aerial seeding of bottomland hardwoods is considered a truly

Figure 7.6. Crop duster used for sowing acorns.

effective technique. One problem with aerial seeding is that the standard hopper and gate system on cropdusters cannot handle more than one size class of acorns at a time. Unless a more flexible system is developed that allows several sizes of acorns to be sown simultaneously, multiple passes over a field will be required.

Applied research on calibration of hoppers, gates, and air speeds is needed to ensure desired sowing rates are achieved. Also, definitive guidelines need to be developed on the best ways to ensure that seed is buried deeply enough. For example, the field cultivator worked better than disking when the soil moisture was high. In short, testing of aerial seeding methods needs to be expanded and replicated over a variety of site and soil types.

Selected References

Haynes, R.J., Bridges, R.J., Gard, S.W., Wilkins, T.W., and Cook, H.R., Jr., 1995, Bottomland hardwood reestablishment efforts of the U.S. Fish and Wildlife Service: Southeast Region, *in* Fischenich, J.C., Lloyd, C.M., and Palermo, M.R., eds., Proceedings of the National Wetlands Engineering Workshop: Vicksburg, Miss., U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report WRP-RE-8, p. 322-334.

Johnson, R.L., and Krinard, R.M., 1985a, Oak seeding on an adverse site: New Orleans, La., U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Research Note SO-319, 4 p.

Johnson, R.L., and Krinard, R.M., 1985b, Regeneration of oaks by direct seeding, *in* Proceedings of the Third Symposium of Southeastern Hardwoods: Atlanta, Ga., U.S. Department of Agriculture, Forest Service, Southern Region, p. 56-65.

Johnson, R.L., and Krinard, R.M., 1987, Direct seeding of southern oaks: a progress report, *in* Proceedings of the Fifteenth Annual Hardwood Symposium of the Hardwood Research Council, May 10-12, 1987, Memphis, Tenn.: Memphis, Tenn., Hardwood Research Council, p. 10-12.

Philo, G.R., 1982, Planting stock options for forestation of surface-mined lands, *in* Kolar, C.A., and Ashby, W.C., comps., Post-Mining Productivity with Trees, Proceedings of a Seminar in the Department of Botany, March 31-April 1-2, 1982, Carbondale, Ill.: Carbondale, Ill., Southern Illinois University, p. 65-74.

Richards, T.W., Wittwer, R.F., and Graves, D.H., 1982, Direct-seeding oaks for surface-mine reclamation, *in* Kolar, C.A., and Ashby, W.C., comps., Post-Mining Productivity with Trees, Proceedings of a Seminar in the Department of Botany, March 31-April 1-2, 1982, Carbondale, Ill: Carbondale, Ill., Southern Illinois University, p. 57-62.

Savage, L., Anthony, J., and Buchholz, R., 1996, Rodent Damage to Direct Seeded Willow Oak in Louisiana, *in* Eversole, A.G., ed., Proceedings of the Fiftieth Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, October 5-9, 1996, Hot Springs, Ark.: Southeastern Association of Fish and Wildlife Agencies, p. 340-349.

Smith, D.M., 1986, The practice of silviculture (8th ed.): New York, John Wiley and Sons, 527 p.

Toumey, J.W., and Korstian, C.F., 1942, Seeding and planting in the practice of forestry: New York, John Wiley and Sons.

Wood, F.A., 1998, First-year performance of direct-seeded Nuttall and willow oak in response to flooding in a farmed wetland of the Mississippi delta: Mississippi State University, M.S. thesis, 124 p.

Chapter 8: Planting Seedlings

Planting tree seedlings is an old, well-established method of reforestation. The primary advantage of using seedlings is that, overall, the chances for success appear to be higher than with direct seeding. Also, the initial development of the trees is usually somewhat faster. The main disadvantage is the higher cost, since seedlings must first be raised in a nursery (or dug up from under existing stands; see Chapter 9).

Although chances for success are high when planting seedlings, incorrect or careless handling or planting of seedlings can easily result in an expensive failure. In addition to selection of the appropriate species for the site, the keys to successful establishment of tree seedlings are obtaining good quality seedlings, taking proper preplanting care of the seedlings, and using proper planting techniques.

Choice of Seedling Type

There are two major types of seedlings used in planting operations, bare-root and containerized. Bare-root seedlings have been separated from the soil in which they were growing at the nursery by a process known as “lifting,” which usually involves cutting the tap root 15-30 cm (6-12 inches) below the soil surface and mechanically loosening the soil around the roots. Containerized seedlings come in a variety of forms, ranging from very small seedlings in small tubes to larger seedlings (or saplings) in gallon-sized or larger pots or bags (fig. 8.1). The choice of seedling type depends to a large degree on the conditions at the restoration site. In some situations bare-root seedlings will be preferred, and in other situations containerized stock will be preferred.

Bare-Root Seedlings

Bare-root seedlings can be expected to survive and grow well as long as the planting site is not too drought-prone and the soil conditions are not otherwise unfavorable. They are less expensive, lighter, easier to transport, and generally easier to plant than containerized seedlings. Bare-root seedlings must be planted during the dormant season, December through mid-March. Some species, such as baldcypress, can be planted along water bodies in flood prone areas later in the season as the water recedes.

Bare-root hardwood and cypress seedlings should have a top height of at least 46 cm (18 inches). The root collar (the part of the root just below ground level) should be at least 0.6 cm (1/4 inch) thick. When possible, though, selected seedlings should have a minimum top height of 60 cm (24 inches) and a minimum root collar diameter of 0.9-1.3 cm (3/8 to 1/2 inch). The use of larger seedlings may be especially important for projects where no site preparation or weed control will be carried out. Although larger seedlings may be more expensive, their use will still generally be cost-effective because mortality will be lower, meaning that less seedlings need to be planted. The cost of planting is usually considerably more than the cost of seedlings; therefore, the higher cost of large, good-quality seedlings may be more than offset by the reduced expense of planting a large number of seedlings. On the other hand, seedlings that are much larger than about 90 cm (36 inches) in top height are difficult to handle and plant. Seedlings in the 60-90 cm (24-36 inches) range are ideal for most applications.

In addition to their large size, bare-root seedlings should have a good balance between shoot size and root volume. The roots should be healthy looking, well-developed (i.e., have several lateral roots greater than about 1 mm [1/25 inch] in diameter), and pruned to a length of about 20 cm (8 inches) (fig. 8.2). Seedlings that have too much top growth for the roots to support will often die back and resprout from the root collar. It is preferable to top prune the seedlings back to a favorable size.

Figure 8.1. Selection of larger sized containers for growing seedlings.

Figure 8.2. Good quality bare-root oak seedlings.

In some cases, it might be desirable to obtain top-pruned, bare-root seedlings. Top-pruned seedlings are cheaper to ship and easier to plant, and they may have better survival or less dieback on sites prone to drought stress. Seedlings can be top-pruned after purchase using simple equipment such as a machete. In general, though, few differences in long-term performance have been found, so the primary advantages of top-pruning may be in lower shipping costs and easier planting.

Containerized Seedlings

When planting on harsher sites and/or outside of the dormant season, containerized seedlings are preferable because their roots are protected by the same soil they were grown in at the nursery. This can lessen the initial shock of transplanting and ensures that the roots of the seedlings remain moist for a longer period after planting.

Containerized seedlings are used most extensively in peninsular Florida, where prolonged dry, hot seasons occur in late spring and again in late autumn. Small containers are also gaining in popularity in the Lower Mississippi Alluvial Valley. The U.S. Army Corps of Engineers has planted over 800 ha (2,000 acres) with containerized stock. Most containerized seedlings are grown in gallon-sized pots, and the seedlings are outplanted upon attaining heights of 45-125 cm (18-48 inches); however, a wide variety of small containers have been recently developed for seedling propagation. Containerized seedlings offer the advantage of reducing transplant shock and have a wider planting window. Burkett (1996) suggested that the more extensively developed root system of containerized stock may offer potential advantages when seedlings are planted at sites prone to drought. Also, inoculation of the containerized seedlings with mycorrhizae slightly but significantly enhanced root fibrosity (Burkett, 1996). If grown in too small of a container, however, containerized seedlings can often be root bound with the roots curled around the inside of the pot (fig. 8.3). Root-bound seedlings tend not to form vigorous root systems when planted. They may grow for several years as vigorous saplings and then suddenly die, their roots apparently unable to supply adequate water during especially dry periods. Quality is

Figure 8.3. Root-bound seedling grown in a 1-gallon container.

hard to summarize for containerized seedlings because of the variety of container types. In general, seedlings should have good root development but should not be root bound. There should be a good balance between root mass and size of the shoot.

Recently, restorationists in Florida have been planting sack-grown trees with much better success. The thin plastic sacks are 0.3 m (12 inches) long cylinders with drain holes at the bottom (fig. 8.4). Roots of sack-grown trees grow downward without curling. After the roots have reached the sack bottom, the seedling is approximately 60 cm (24 inches) tall and ready for planting. Gasoline-powered soil augers drill holes into which the root ball fits snugly. The roots are deep enough when planted to reach moist soil layers during dry seasons. Experimental plot studies by the Florida Institute of Phosphate Research are corroborating the generally superior results of restorationists who have tried sack trees. Costs of growing and planting sack trees are lower than for gallon-sized seedlings, but start-up costs are much higher. The substitution of fabric containers for sacks is still more promising because aeration and root development are more uniform than in plastic sacks. No large-scale trials with fabric containers, however, have been tried.

Another seedling type, used in Florida, is the tubeling or "plug." Plugs have features of both bare-root seedlings and containerized stock. Their densely compacted roots enclose only a very small amount of soil (fig. 8.5). They are grown in specially designed flats, called "liners," from which they are removed before delivery at a project site. Planting of plugs can be accomplished with a bulb planter that extracts a plug of soil, leaving a cylindrical hole (fig. 8.6). They combine the convenience and low cost of bare-root seedlings with a somewhat higher probability of survival on harsh sites. They are less likely to survive during prolonged dry seasons, however, than seedlings grown in larger containers. For this reason,

Figure 8.4. Carolina ash seedlings grown in plastic sacks.

Figure 8.5. Dahoon tubelings removed from their pots and ready for planting.

Figure 8.6. A bulb planter is a commonly used hand tool for planting seedlings.

most restorationists opt for more traditional types of containerized stock. No matter what type is used, only good quality seedlings should be planted. The importance of this cannot be overemphasized. Even if everything else is done right on a restoration project, the project will still be a failure if poor quality seedlings are used.

Handling Seedlings

As discussed, bare-root seedlings have important advantages, but they require especially careful handling. Because their roots are exposed, care must be taken to prevent them from drying out. The seedlings will typically come from the nursery in bundles of about 50 to 200 (up to 400), ideally with their roots packed together and wrapped in sphagnum moss or some type of water-retaining material and the whole bundle wrapped in waterproof paper bags or cardboard boxes.

If the seedlings are not planted immediately, they should be stored at a temperature slightly above freezing, preferably in a cold storage unit. Storage in a barn, shed, or dense shade will be adequate for a few days to a few weeks, as long as the seedlings stay reasonably cool and the roots are not allowed to freeze or dry out.

Another method of temporary storage is “heeling-in.” Using this method, seedlings are spread out in a V-shaped trench (dug in a shaded location), and their roots covered with loose soil. The soil is then watered and gently packed down to remove any air pockets, and the roots are kept moist throughout the storage period.

Only as many seedlings as can be planted in one day should be taken to the field. The seedlings should either be taken out of the nursery-supplied bundles and planted immediately or transferred in small groups to a bucket or a planting bag (fig. 8.7). A group of seedlings should never be carried by hand while planting. Smith (1986, p. 296) wrote, “In any step in handling bare-rooted seedlings it is vital that the roots always remain visibly moist. They should not be uncovered for more than 2-3 minutes at any time whether it is just after lifting, in the packing shed, or when it is finally planted. Even briefer exposure is preferable . . . Tree roots are so easily killed

Figure 8.7. A good field method to protect the roots of seedlings is to carry them in a planting bag.

that it is remarkable indeed that many millions of bare-rooted seedlings survive planting."

Although containerized seedlings are less susceptible to freezing or drying out, they can also be damaged or destroyed by careless handling. If containerized seedlings are transported in a closed truck, they can become overheated, especially when planting in late spring or summer. On the other hand, if seedlings are transported in an open vehicle they can become desiccated or damaged by having their stems and leaves blown about in the wind. Seedlings should be transported in ways that provide good ventilation (especially on hot days so that they do not overheat), although too much wind directly on the leaves causes desiccation.

Timing of Planting

The best time to plant bare-root seedlings is when they are dormant and the soil is moist. Generally, planting conditions in the South are most suitable from January through March. Planting can usually be done in November and December, especially for species which have lost their leaves, such as green ash and sycamore, but planting earlier than November is not usually recommended. Planting can also be done later than March if the seedlings are kept in cold storage and the roots kept moist until planting. Planting bare-root seedlings that have broken dormancy is not recommended.

The most frequent limitations on planting are excessive cold and flooding. Bare-root seedlings should not be planted in subfreezing temperatures. The more flood-tolerant species can be planted in shallow water, up to about 15 cm. Disked soils should be moist but not flooded.

An advantage of containerized seedlings is that they can be planted safely once they have broken dormancy. It is still advisable to plant in the winter or early in the growing season while the temperatures are cool and the soil is moist, but as long as conditions are not excessively hot and dry, later plantings will usually be successful. In Florida, containerized seedlings are also successfully planted at the beginning of the summer rainy season, which usually starts in June.

Spacing

Spacings of planted seedlings will depend on objectives. Spacings of 3 × 3 m (10 × 10 ft) or closer are often used for wood production and may be required to ensure the number of surviving seedlings stipulated in some permits. In other cases, wider spacings can be used, such as 3.6 × 3.6 m (12 × 12 ft), 4.5 × 4.5 m (15 × 15 ft), or 6 × 6 m (20 × 20 ft). The standard spacing for the Natural Resources Conservation Service and the U.S. Fish and Wildlife Service is 3.6 × 3.6 m (12 × 12 ft). Because fewer seedlings are required per hectare (see table 7.2), wider spacings are more economical and may be just as effective in meeting the project objectives. Also, using a wider spacing will allow openings for the natural invasion of light-seeded tree species. Wide spacing of the seedlings is one potential, but not always reliable, method for increasing species diversity on the restoration site.

As mentioned previously, making the spacing very precise is undesirable unless timber production is the primary goal or weed control by mowing or disking is planned. A tree farm appearance should be avoided if wildlife, aesthetics, or a more natural appearing forest are the primary goals.

Planting with Hand Tools

Bare-root seedlings can be planted using a dibble bar or sharpshooter shovel (fig. 8.8). The proper technique for use of these tools is shown in fig. 8.9. Occasionally, other tools are used, such as grub hoes, mattocks, and hoedads. Regardless of what type of tool is used, roots should be placed in the hole so they can spread out naturally; they should not be twisted, balled up, or bent.

Figure 8.8. Bare-root seedlings can be planted using a sharpshooter shovel, dibble bar, or bulb planter.

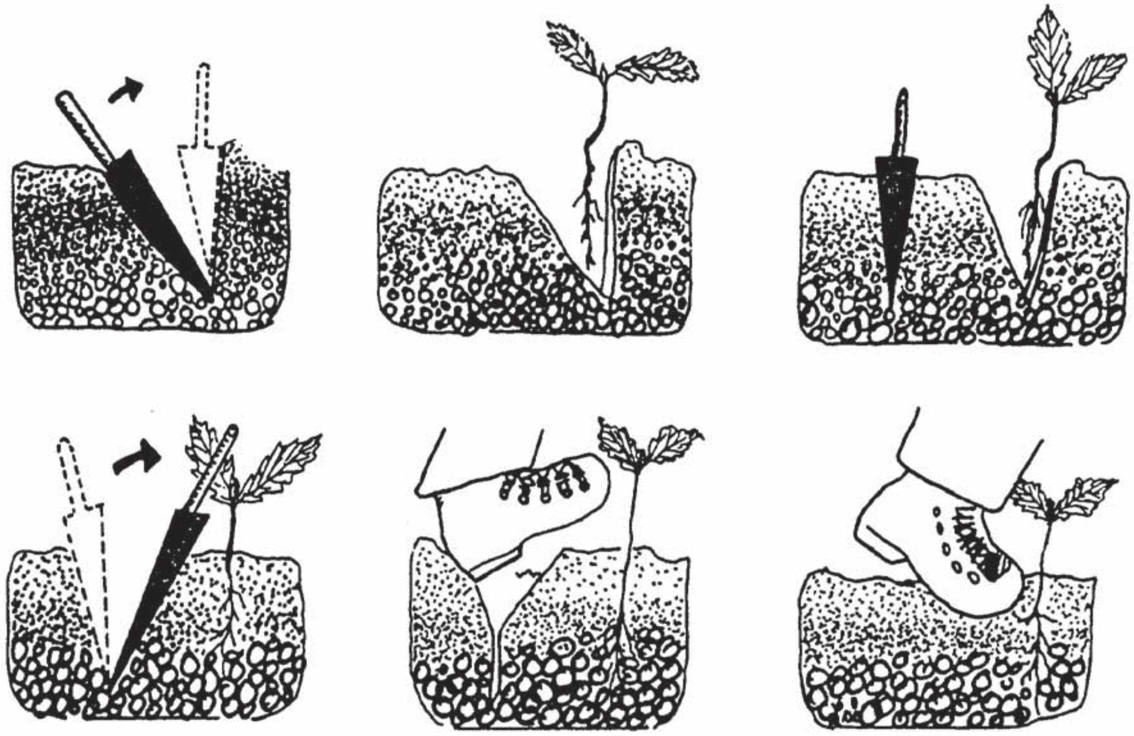


Figure 8.9. Planting technique for use with hand tools.

Moist soil should then be firmly packed around the roots. Hand planting of most types of containerized seedlings is done with a shovel, although specialized hand tools have been developed for some of the smallest types of containers.

Planting a tree by hand is a simple task but nevertheless is often done incorrectly. If a crew of inexperienced tree planters is used, it is essential to demonstrate clearly to them the proper way to plant. The crew should be supervised closely, especially the first time they plant and late in the day after they have become tired and perhaps careless.

Seedlings should be planted with their root collars just below the soil surface (fig. 8.10a). One of the most common planting mistakes is planting seedlings either too deep (fig. 8.10b) or not deep enough (fig. 8.10c). Another common mistake is digging a hole too shallow for proper root placement. If this occurs, roots may be bent upwards, or "J-rooted" (fig. 8.10d), which results in roots not penetrating deeply enough into the soil to protect the tree from windthrow or drought. Additional mistakes are planting so that settling soil leaves the root-collar exposed and leaving an air pocket near the roots after closing the hole (fig. 8.10e), which allows the roots to dry out.

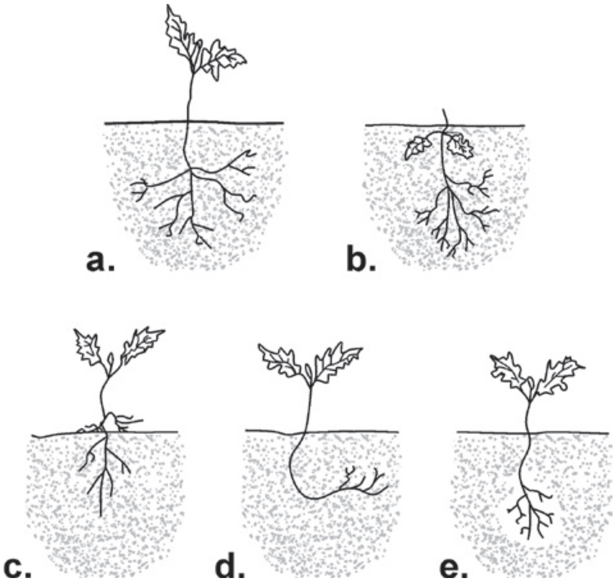


Figure 8.10. It is critical that tree seedlings be (a) planted properly; they should not be planted (b) too deep, (c) too shallow, (d) with roots bent upwards, or (e) with air pockets.

When planting containerized seedlings, the container should be removed first, although this may not be as critical if the container is biodegradable. If a biodegradable container is not removed, it should be trimmed so as not to protrude above the ground, since this can cause drying of the soil through a process known as “wicking.” When seedlings are removed from their containers, any roots encircling the outside of the root ball should be loosened up and pointed outwards and downwards or removed. Otherwise, these roots will not spread out properly and could even girdle the stem. The seedlings should be planted in a hole deep enough so that the tops of the root balls are slightly below ground level. The final step in planting a containerized seedling is to fill the hole and pack the soil firmly around the root ball to remove any air pockets and keep the seedling pointed straight up.

Just like the number of seeds a single person can plant in a day will vary widely, the number of seedlings that can be planted will also vary, depending on factors such as the size and type of seedling, degree of site preparation, spacing, soil type, soil condition, weather, experience and physical condition of the planter, and distance the planter has to carry seedlings before being able to start planting. On a clean, level site, a planter should be able to plant at least 500 to 800 bare-root seedlings per day or sometimes up to 1,000 seedlings per day for planters with more experience. Because planting quality can diminish through the day as the crew becomes tired, planting quality should be monitored more closely after several hours of work. The number of seedlings planted per day will be much less if containerized seedlings are being planted, the locations of individual seedlings must first be marked, or if planting conditions are suboptimal.

Planting with Machines

When site conditions are favorable, machine planters can speed up the planting of bare-root seedlings dramatically on soils other than heavy clays. An experienced crew of two or three may plant from 4,000 to 10,000 seedlings a day with a machine planter. Also, survival will often be better than that achieved by a large, relatively inexperienced crew of hand planters. Some of the newer planting machines perform well in heavy clays, planting 5,000 to 8,000 seedlings per day with an experienced crew.

One disadvantage of machine planters is that intensive site preparation may be required. Machines cannot readily operate where there are stumps or heavy debris. On heavy clays, planters may become clogged or be unable to penetrate deeply enough to ensure that the roots are completely covered. Also, the furrows dug by the planter may reopen in the summer when the clay dries out, thereby exposing the roots. On abandoned agricultural

Figure 8.11. Mechanical seedling planter.

fields, no site preparation may be needed for mechanically planting seedlings. Machine planting is becoming a more extensively used reforestation method and, as new tools are being developed, may become preferred even on heavy clay soils as long as soil conditions (e.g., moisture) remain favorable.

Another disadvantage of mechanical planters is their high cost, which is prohibitive for most small planting projects. It is possible in some areas to rent or borrow a planter; a good source of information on the local availability of planters is the county, parish, or district forester.

An example of one type of mechanical planter is shown in fig. 8.11. Other types of planters, including some that are considerably less expensive, are available through sources such as forestry supply companies.

The planting rate for containerized seedlings may also be increased by using machines to dig the planting holes. Machines that have been used for this purpose range from augers to backhoes, depending on the size of the planting stock.

Selected References

Burkett, V., 1996, Effects of flooding regime, mycorrhizal inoculation and seedling treatment type on the establishment of Nuttall oak (*Quercus nuttallii* Palmer): Nacogdoches, Tex., Stephen F. Austin State University, Ph.D. dissertation, 140 p.

Burkett, V., and Williams, H., 1998, Effects of flooding regime, mycorrhizal inoculation and seedling treatment type on first-year survival of Nuttall oak (*Quercus nuttallii* Palmer), *in* Waldrop, T.A., ed., Proceedings of the Ninth Biennial Southern Silvicultural Research Conference, February 25-27, 1997, Clemson, S.C.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-20, p. 289-294.

Conner, W.H., Toliver, J.R., and Askew, G.R., 1993, Artificial regeneration of baldcypress in a Louisiana crayfish pond: Southern Journal of Applied Forestry, v. 17, no. 1, p. 54-57.

DeYoe, D., Holbo, H.R., and Wadell, K., 1986, Seedling protection from heat stress between lifting and planting: Western Journal of Applied Forestry, v. 1, p. 124-126.

Howell, K.D., and Harrington, T.B., 1998, Regeneration efficiency of bareroot oak seedlings subjected to various nursery and planting treatments, *in* Waldrop, T.A., ed., Proceedings of the Ninth Biennial Southern Silvicultural Research Conference, February 25-27, 1997, Clemson, S.C.: Asheville, N.C., U.S. Department of Agriculture, Forest Service Southern Research Station, General Technical Report SRS-20, p. 222-226.

Humphrey, M.N., 1994, The influence of planting date on the field performance of 1-0 bareroot, container grown, and direct seeded *Quercus nuttallii* Nuttall oak on sharkey soil: Alcorn State University, Miss., M.S. thesis, 52 p.

Johnson, R.L., and Krinard, R.M., 1985, Oak regeneration by direct seedling: Alabama's Treasured Forests, v. 4, no. 3, p. 12-15.

Rietveld, W.J., 1989, Transplanting stress in bareroot conifer seedlings: its development and progression to establishment: Northern Journal of Applied Forestry, v. 6, p. 99-107.

Smith, D.M., 1986, The practice of silviculture (8th ed.): New York, John Wiley and Sons, 527 p.

South, D.B., 1996, Top-pruning bareroot hardwoods: a review of the literature: Tree Planters' Notes, v. 47, no. 1, p. 34-40.

White, D.P., Schneider, G., and Lemmien, W., 1970, Hardwood plantation establishment using container grown stock: Tree Planters' Notes, v. 21, no. 2, p. 20-25.

Williams, H.M., and Craft, M.N., 1998, First-year survival and growth of bareroot, container, and direct-seeded Nuttall oak planted on flood-prone agricultural fields, *in* Waldrop, T.A., ed., Proceedings of the Ninth Biennial Southern Silvicultural Research Conference, February 25-27, 1997, Clemson, S.C.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-20, p. 300-303.

Chapter 9: Other Options for Revegetation

Although direct seeding and planting seedlings are the two most widely used techniques for reestablishing bottomland hardwood trees, there are several other regeneration methods available. In this chapter, four methods of revegetation are covered: use of cuttings, transplanting, topsoiling, and natural regeneration.

Cuttings

Several species of bottomland hardwoods can be readily propagated with cuttings, or short lengths of young shoots. Cuttings can be rooted first in a nursery and then planted as seedlings, or they can be directly planted on the restoration site. Cuttings of black willow, cottonwood (fig. 9.1), green ash, and sycamore have been successfully planted as unrooted cuttings. For most other species, using rooted cuttings is likely to be more successful.

Cuttings should be obtained in the dormant season and can either be stored until spring or planted right away. Effective temporary storage methods include placing the cuttings in cool water or covering them with wet burlap or similar material. Long-term storage can be achieved by bundling cuttings and refrigerating them in moist sand or plastic bags.

Success has been obtained with cuttings ranging in size from 10-15 cm (4-6 inches) “slips” to poles of 2.5-3 m (8-10 ft) in length, depending on the species. In general, cuttings 40-50 cm (16-20 inches) long and no less than about 0.6 cm (1/4 inch) in diameter at the top end should be used. Larger cuttings may be necessary on sandy or drought-prone soils.

Cuttings are usually planted vertically with the buds pointing upwards and the tops of the cuttings projecting 5-10 cm (2-4 inches) above the soil surface. Cuttings of cottonwood, green ash (fig. 9.2), sycamore, and black willow have also been planted horizontally, in slits about 2.5-5 cm (1-2 inches) deep.

Cuttings should be planted when dormant because survival generally decreases substantially if they are planted once the buds have begun to open. Ideal planting sites are moist but not flooded for long periods. Seedlings usually survive better than cuttings in areas with extensive flooding in the growing season.

Figure 9.1. Bundle of cottonwood cuttings.

Transplants

Seedlings or saplings transplanted from natural forests (also known as “wildlings”) are sometimes used in restoration projects. Depending on size, the planting material can be transplanted by using hand tools or heavy equipment such as tree spades (fig. 9.3) or backhoes. Unless the transplanting is done very carefully, mortality will be high, and surviving transplants will suffer so much shock that they will not begin to grow for a year or more after transplanting.

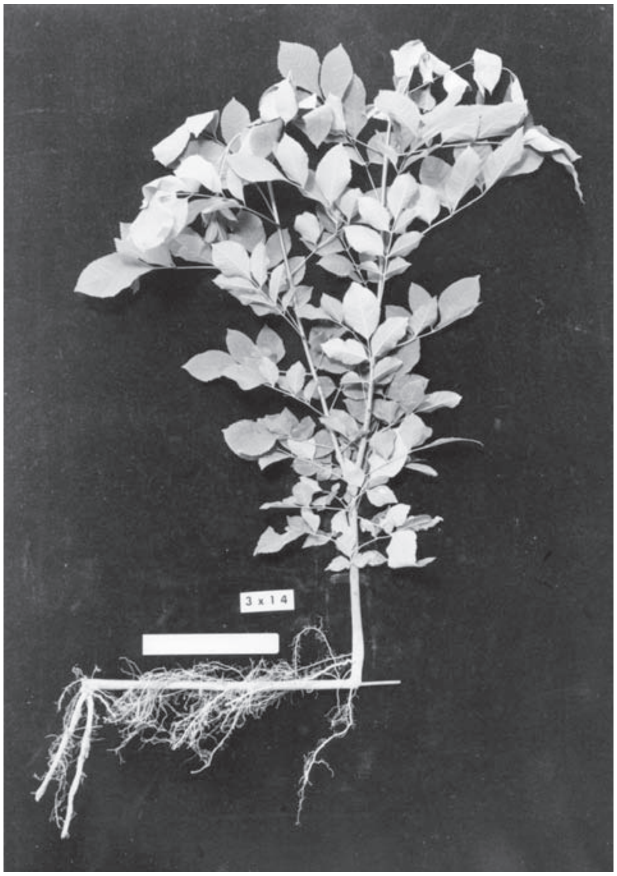


Figure 9.2. One-year-old green ash seedling grown from a horizontally planted cutting.

Figure 9.3. Tree spade used for planting large saplings or small trees. Photo courtesy of Dr. Schilling, Louisiana State University School of Forestry.

Transplanting is most successful when done in the dormant season. The roots of large transplants (those with basal diameters larger than about 5 cm) should be balled and bagged before transporting to the restoration site. Smaller transplants can be transported without being placed in bags, as long as their roots are protected from drying out. If possible, transplants should be taken from open sites, rather than from under dense forest canopies, since the chances of shock caused by exposure to full sunlight and high temperatures will be somewhat reduced.

Transplanting has been most frequently employed on restoration projects in Florida (Clewell, 1981; Posey and others, 1984). Clewell (1981) suggests that about 200 saplings can be transplanted in a week using a tree spade.

Some restorationists working in Florida observed that transplanting can also introduce desirable understory plants (Clewell, 1999). A few species appear to become successfully established by transplanting yet not by topsoiling, perhaps because the soil surrounding the seedling's or sapling's roots is kept more intact than it is with topsoiling. Of course, undesirable species may also be introduced by transplanting, depending on the species composition of the donor site. Another advantage of transplanting is that the larger size stock provides perches for birds and therefore provides vertical structure and enhances natural seed dispersal of some plant species.

Topsoiling

Topsoiling involves the transfer of topsoil from a natural wetland site to a restoration site. With this method, topsoil is spread out over a restoration site in the hopes that the seeds, stumps, rhizomes, and other plant parts contained within it will produce new plants. Topsoiling is commonly employed in marsh restoration but has been used much less frequently to restore forested wetlands.

A major advantage of topsoiling is that it has the potential to introduce many of the native understory tree, shrub, and herbaceous species that ordinarily are not planted. Also, it may result in successful introduction of mycorrhizal fungi or soil biota that enhance soil conditions.

There are several possible disadvantages, however, of topsoiling. A potentially serious drawback is that topsoiling requires disturbance of an intact wetland. Unless the topsoil can be taken from a wetland about to be destroyed, it means that one wetland has to be damaged to restore another. A second disadvantage is that species composition is difficult to predict and control. In some cases, topsoiling may also introduce exotic or otherwise undesirable species.

A variety of methods have been employed to remove topsoil from the donor site, transport it, and spread it on the restoration site. If tree cover exists on the donor site, the first step is usually removal of the trees. The topsoil can then be removed using equipment such as draglines, scrapers, or bulldozers. Only the top 20-30 cm (8-12 inches) of topsoil should be removed because below that depth the number of viable seeds drops off significantly.

Transportation methods for moving topsoil will depend on the distance between the donor and the restoration sites. Dump trucks are generally used for transportation distances in excess of 1.6 km (1 mile). Scrapers (fig. 9.4) can be cost effective for shorter hauls, although they do not work well in very wet situations or with heavy clay soils that may require additional heavy equipment to push or pull them. For very small distances, simply pushing the topsoil to the restoration site with a bulldozer or transporting it with a front end loader may be effective. Light, crawler-mounted bulldozers (fig. 9.5)

Figure 9.4. Scrapers are useful for short-distance transport of topsoil.

are recommended for spreading the topsoil on the restoration site because they minimize soil compaction.

Topsoil should be spread on the restoration site to a depth of about 10-20 cm (4-8 inches). Depths shallower than about 7 cm (3 inches) may not contain enough seeds and other plant material to ensure adequate plant establishment. Spreading topsoil to depths much greater than 20 cm (8 inches) may actually be counterproductive because costs become excessive, and many seeds will be buried too deep for germination.

In general, topsoiling will be most successful on sites where the topsoil will remain moist. In most of the Southeast, spring is the best time of year for topsoiling. On exposed sites where the soil surface is likely to dry out, irrigation will be required. In most situations, topsoiling should be viewed as a useful secondary means of revegetation with one of the other methods used as the primary means of reestablishing trees.

The term “mulching” is often used when referring to topsoiling, but mulching is technically a broader term that describes the process of applying any organic or inorganic material to the soil surface. Examples of other materials occasionally used as mulches include agricultural residues such as straw, hay, or bagasse and wood residues such as bark, sawdust, or wood chips.

Natural Regeneration

Natural regeneration—allowing vegetation to become established from natural sources—is an attractive alternative for restoration because the cost of planting is avoided. Also, any plants that become established on the restoration site should be well adapted to the site. If conditions are suitable, natural regeneration can be quite rapid, but highly degraded sites or sites far from a seed source will take much longer to naturally revegetate.

Many restoration projects rely on natural regeneration for all or part of vegetation establishment. In the Lower Mississippi Alluvial Valley and on some western Kentucky coal-mined sites, for example, only hard mast producing tree species are planted on most old-field restoration projects, and natural regeneration is relied upon for establishment of light-seeded tree species, understory tree species, and herbaceous vegetation.

Sites where use of natural regeneration is most appropriate include small or narrow sites where most of the site is no farther than about 70-90 m (75-100 yds) from an existing forest and sites that are subject to frequent flooding. A general rule of thumb is that natural regeneration will succeed without intervention in areas that are within a distance from an existing forest no greater than

Figure 9.5. Bulldozer spreading topsoil at Hall's Branch restoration site.

twice the height of the dominant canopy trees. Although disking is often used to reduce competition for the newly planted seedlings, Allen and others (1998) showed that disking of old-field sites reduced the number of invading woody seedlings that became established. They proposed that the added soil drying and elimination of microrelief (old bedding rows) resulted in reduced opportunity for seedling establishment.

Seedlings of species not dispersed by wind are often missing from naturally regenerated stands, or stands show a clumped distribution related to bird roosting and/or animal eating habits. Providing perches, planting of a few large trees, and even placing snags on a restoration site can encourage the natural regeneration of plant species dispersed by birds.

The major disadvantage of natural regeneration is that species composition is difficult to control. Light-seeded or undesirable species may need to be thinned out to allow the higher value heavy-seeded species time and space to become established and grow.

Another potentially serious disadvantage is the longer time period required for establishment of tree cover. A naturally regenerated site is likely to go through a successional process where the site is first dominated by annual plants, then perennial herbaceous plants, then shrubs and light-seeded, shade-intolerant tree species, and finally heavy-seeded and shade-tolerant tree species. On large old-field sites, the herbaceous plants may dominate a site for 10 years or more. On other types of sites (e.g., clay settling basins), willows, boxelder, swamp red maple, river birch, or other species that provide less wildlife value (compared with hard mast species) may dominant for many years (see table 4.1).

Selected References

Allen, J.A., 1997, Reforestation of bottomland hardwoods and the issue of woody species diversity: Restoration Ecology, v. 5, p. 125-134.

Allen, J.A., McCoy, J., and Keeland, B.D., 1998, Natural establishment of woody species on abandoned agricultural fields in the Lower Mississippi Valley: first- and second-year results, *in* Waldrop, T.A., ed., Proceedings of the Ninth Biennial Southern Silvicultural Research Conference, February 25-27, 1997, Clemson, S.C.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-20, p. 263-268.

Battaglia, L., 1991, Early secondary succession in a bottomland hardwood area: Northeast Louisiana University, Monroe, La., M.S. thesis, 82 p.

Bonck, J., and Penfound, W.T., 1945, Plant succession on abandoned farm land in the vicinity of New Orleans, Louisiana: American Midland Naturalist, v. 33, p. 520-529.

Clewell, A.F., 1981, Vegetational restoration techniques on reclaimed phosphate strip mines in Florida: Wetlands, v. 1, p. 158-170.

Clewell, A.F., 1999, Restoration of riverine forest at Hall Branch on phosphate-mined land, Florida: Ecological Restoration, v. 7, no. 1, p. 1-14.

Dirr, M.A., and Heuser, C.W., Jr., 1987, The reference manual of woody plant propogation: from seed to tissue culture: Athens, Ga., Varsity Press, 239 p.

McClanahan, T.R., and Wolfe, R.W., 1993, Accelerating forest succession in a fragmented landscape: the role of birds and perches: Conservation Biology, v. 7, p. 279-288.

Posey, D.M., Jr., Goforth, D.C., and Painter, P., 1984, Ravenwood shellrock mine: wetland and upland restoration and creation, *in* Webb, F.J., ed., Proceedings of the 11th Annual Conference on Wetland Restoration and Creation, 1984: Tampa, Fla., Hillsborough Community College, p. 127-134.

Wolfe, R.W., 1990, Seed dispersal and wetland restoration, *in* Odum, H.T., Best, G.R., Miller, M.A., Rushton, B.T., Wolfe, R.W., Bersok, C., and Friertag, J., eds., Accelerating natural processes for wetland restoration after phosphate mining: Bartow, Fla., Florida Institute of Phosphate Research, p. 51-95.

Chapter 10: Establishing Native Undergrowth Vegetation

Most species of plants occurring in forests are not trees. For example, a bottomland hardwood forest in western Kentucky contained 143 species, of which 80 (56%) were terrestrial herbs, and only 38 (27%) were overstory trees; the remainder were shrubs and woody vines. In hardwood forests along the upper reaches of the Alafia River near Tampa, Florida, 71% of the 409 plant species were terrestrial herbs (292 species), consisting largely of ferns, sedges, grasses, and wildflowers (Clewell and others, 1982). Only 36 plant species were overstory trees. The remaining 81 species were small understory trees, shrubs, woody vines, and epiphytes.

These and similar observations elsewhere demonstrate that bottomland hardwood forest restoration is incomplete until a representative contingent of undergrowth species is established. This conclusion complicates revegetation activities, which, in the past, have focused on tree planting. Four basic questions are immediately raised: (1) are understory species so important ecologically that we should be concerned about them? (2) will undergrowth species colonize a newly restored forest by means of natural regeneration? (3) how many undergrowth species should be established to restore a forest adequately? and (4) how can undergrowth species be intentionally established at restoration project sites? This chapter attempts to answer these questions.

Although the importance of understory species is widely recognized by virtually all involved with bottomland hardwood restoration, some are of the opinion that, over time, the overstory plantings will develop conditions conducive to the natural establishment of understory species from an existing seedbank or from species brought into the area by wind, wildlife, or floodwater. Such natural invasion of understory species has not been conclusively demonstrated, but most restoration projects are still relatively young. The restorationist must determine if the time and resources spent on physically establishing understory species are well spent or if they may be better spent on other projects.

Ecological Importance of Understory Plants

Biodiversity

The aforementioned 292 species of terrestrial herbs occurring along Florida's Alafia River were tallied in sample areas totaling only 4.6 ha (11.3 acres). In spite of this small sample size, these herbs represented 8% of all vascular plant species known from the entire state of Florida. This floristic wealth vividly demonstrates the importance of forest undergrowth with respect to regional biodiversity. If ample biodiversity is a goal of restoration, then undergrowth cannot be ignored. Undergrowth vegetation that would likely overtop newly planted tree seedlings may best be planted one to several years later to allow the tree seedlings time to attain sufficient height to be above the undergrowth.

Ecological Functions

When considered by forest ecologists, the numerous undergrowth species are generally treated collectively by stratum or by life form. The functional roles of individual species are poorly known because the autecology (relationship between an individual species and its environment) of very few have been investigated. Perhaps the best known functional roles of undergrowth are those pertaining to wildlife habitat in terms of providing cover, forage, and nesting sites. Another obvious benefit provided by undergrowth is anchorage of the soil, which counters the erosive forces of runoff and overbank flooding. Undergrowth vegetation also contributes friction (roughness) to the forest surface, thereby retarding the velocity of floodwater. Anchorage and reduction of flood velocities both contribute to substrate stability and encourage sedimentation on floodplains. Sedimentation, in turn, increases the reservoir of nutrients available to vegetation.

Another function of the undergrowth that is not well documented but may contribute substantially to herbivore control and food chain stability is the harboring of predacious arthropods, mainly insects and spiders. A given species of arthropod spends much of its lifetime inhabiting a particular species of plant. The greater the number of plant species available in an area, the greater the diversity of predacious arthropods. This feature is realized by specialists in the biological control of crop pests. They have found that pest control is enhanced by having a diverse array of native plant species growing in close association with crops. It seems likely that these same predacious insects and spiders are also controlling herbivorous insects that attack native forest trees. Another array of insects associated with floristically diverse undergrowth may serve to pollinate flowers, including those of trees.

Undergrowth vegetation adds complexity to biogeochemical cycling of nutrients because root systems vary from species to species. The greater the diversity in the kinds of root systems, the greater the efficiency of conserving and cycling nutrients released by detrital decomposition. Undergrowth vegetation contributes to detrital biomass upon which soil microflora and detritivores depend. Undergrowth vegetation may also provide benefits to a forest in terms of mycorrhizal associations (a symbiotic relationship between certain fungi and the roots of some plants). In addition, understory vegetation can incorporate a tremendous amount of organic matter into the soil.

In summary, undergrowth plays various roles in forest processes and ecological functions. The importance of these roles may be much greater than has thus far been appreciated.

Natural Regeneration of Undergrowth

A considerable area of bottomland forests has been cleared for agriculture and later left to lay fallow. These lands generally become reforested through the well known process of old-field succession. This natural regeneration includes a substantial development of herbaceous and shrubby vegetation beneath the new forest canopy. Initial undergrowth may consist largely of relatively undesirable species that persist for some time following canopy closure. The undergrowth may be dominated by one or a few species such as goldenrod or wild onions or exotics such as Johnson grass or Japanese honeysuckle.

In contrast, forests occupying undisturbed soils have more undergrowth species, with no one species being disparately abundant. These species tend to be less weedy and more characteristic of deep forest conditions. The weedier species predominate only in disturbed areas, such as in canopy gaps formed by the loss of an overstory tree. Plant species (including overstory trees) that are typical of mature, undisturbed forests are particularly welcome at a restoration project site because they may hasten forest development. For this reason, they may be termed "preferred species."

Even old-growth forests contain contingents of weedier undergrowth species in their canopy gaps that presumably contribute to ecological functioning and should not be discounted. In fact, four categories of undergrowth species can be distinguished, although some species may defy easy classification. Each category description is followed by examples of species for the category, as they occurred in mature forests along the Alafia River (Clewell and others, 1982). These species do not necessarily belong in the same categories in other regions or other forest types. See appendix B for scientific names of all species.

> Category 1. Species largely or entirely restricted in their regional distribution to mature, undisturbed stands (e.g., restricted to a floodplain swamp and also to adjacent mesic forests in the same valley). These are all preferred species: aquatic milkweed, small-spike falsenettle, shiny spikegrass, millet beakrush, water pimpernil, and species of swamplily, bugleweed, lizard's tail, and ferns (*Osmunda, Thelypteris,* and *Woodwardia*).
>
> Category 2. Species that are frequent or at least locally abundant in mature stands and are also abundant in other regional ecosystems (e.g., in a floodplain swamp as well as in open marshes). These are all preferred species: small-fruit beggartick, Mexican water-hemlock, hairlike mock bishop-weed, and species of pickerel weed, smartweed, and burreed.
>
> Category 3. Species occurring much more frequently or abundantly in other regional ecosystems **or** species that are much more abundant in disturbed or early serial stages than in more mature stands. These are **not** preferred species: bushy bluestem, southern carpetgrass, sheathed flatsedge, small dogfennel, Peruvian seedbox, Florida pokeweed, licorice weed, and cattail.
>
> Category 4. Species occurring adventively **or** exotic species, including naturalized exotics. These are **not** preferred species: annual ragweed, American wormseed, crabgrass, Japanese climbing fern, and coffeeweed.

A satisfactory restoration should have a diversity of undergrowth species, including most species from Category 1. In order to determine in which category each species belongs, an experienced botanist will have to use baseline information to group the undergrowth species into the four categories.

Number of Species Necessary for Restoration

A mature, fully restored forest should contain most of the "preferred species," as determined from baseline studies, particularly those from Category 1. In the Alafia River study (Clewell and others, 1982), at least 60 (20%) of the 292 terrestrial herbaceous species qualified as preferred species (i.e., Categories 1 and 2).

Preferred species need not be planted concurrently with trees. Several years will pass before the planted trees can provide the shade that many forest undergrowth plants require for their survival. At that time, an inspection can be made to determine what preferred species have already colonized the project site through natural regeneration. Category 1 species that are absent may then be planted. Preferred species of vines, however, should not be intentionally established. As a class, vines tend to proliferate and become nuisance species at new restoration sites, sometimes threatening the establishment of key tree species.

The remaining question is, how many plants of each preferred species should be established? The answer is only a few of each species. The guiding assumption is that as forested conditions develop, preferred plants will proliferate at the expense of the weedier species, which initially colonized the site and are succumbing to competition from the planted trees. Such proliferation indeed happened at two maturing restoration sites on mined and reclaimed land in central Florida: Hall Branch Restoration (Clewell, 1999) and Dogleg Branch Restoration (Clewell et al., 2000). Clusters of a few plants of each preferred species should be planted at wide intervals to ensure establishment on different parts of the project site. Clustering is needed to ensure cross-fertilization in self-incompatible species. Particularly large project sites can be partitioned into smaller units of perhaps 4 ha (10 acres), in which each preferred species will be established.

Establishing Undergrowth Plantings

Transplanting

There is currently little demand for preferred species of forest undergrowth, and native plant nurseries rarely stock them. Over time, this situation should improve, but presently it is usually necessary to collect seeds, rootstocks, or whole plants from natural populations. Ideally, collections of rootstocks and whole plants should be made as rescue or salvage operations at sites that are scheduled for development. These collections can be transferred directly to the project site, or, if a nursery is available, salvaged stock can be propagated for later distribution. Some Natural Resources Conservation Service facilities are making space available to propagate such native plant materials.

Plant material may have to be removed from donor forests that are not scheduled for development. Plants selected for removal should be spaced far enough apart to prevent localized extirpation. Holes where plants are removed should be filled. A posthole digger frequently proves useful in removing herbaceous plants. This work is labor-intensive and expensive in the absence of volunteer effort. Transplants should be planted in semishade in moist soil. Care should be taken not to leave air pockets around the root balls. For many species, transplanting from the shade of a closed canopy forest to an open field is fatal, therefore, the restoration site must have developed sufficiently enough to provide at least semishaded conditions for these species.

Topsoiling

Topsoiling (mulching with topsoil) is another method of preferred species establishment. The method has been attempted at reclaimed phosphate mines in central Florida. A layer of topsoil only 10 cm (4 inches) thick can provide a bountiful regrowth of vegetation (see topsoiling section, Chapter 9). Topsoiling has proven most successful when the soil is transferred from the donor site directly to the restoration site without stockpiling and when the restoration site is permanently moist or wet (see restoring soil characteristics section, Chapter 5).

Plant propagules (seeds, rootstocks, spores) can quickly lose their viability when stockpiled, owing to poor aeration and to the generation of lethally high internal temperatures. Topsoil that is subjected to seasonal drying after being spread at an open restoration site is unable to sustain most undergrowth plants as they arise from its propagule bank. These plants are adapted to uniformly moist soils. If the amount of topsoil is scarce, it can be transferred from a donor site with a tree spade and planted as if it were a tree. The soil is transferred intact, and undergrowth plants within the soil are less traumatized than they would be if they were spread in a layer. Topsoiling by any method introduces both organic matter and soil microbiota, both of which may hasten soil development, especially on surface-mined sites.

Topsoiling as a technique is largely limited to salvage operations at wetlands that are being cleared for development. Because such sites are rarely permitted for development, the opportunity of using topsoil is becoming rare. Whenever a wetland is permitted for clearing, its topsoil should be salvaged for restoration projects in the vicinity. Unfortunately, hauling costs are prohibitive for transport of topsoil to all but local projects.

Selected References

Altieri, M.A., and Whitcomb, W.H., 1980, Weed manipulation for insect pest management in corn: Environmental Management, v. 4, p. 483-489.

Clewell, A.F., 1999, Restoration of riverine forest at Hall Branch on phosphate mined land, Florida: Restoration Ecology, v. 7, p 1-14.

Clewell, A.F., and Beaman, R.S., 1992, Vegetational restoration at Hall Branch reclamation area, 1990 monitoring report: Brewster Phosphates, 16 p. [Deposited in the Library of the Florida Institute of Phosphate Research, Bartow, FL]

Clewell, A.F., Goolsby, J.A., and Shuey, A.G., 1982, Riverine forests of the South Prong Alafia river system, Florida: Wetlands, v. 2, p. 21-72.

Clewell, A.F., Kelly, J.P., and Coultas, C.L., 2000, Forest restoration at Dogleg Branch on phosphate-mined and reclaimed land, Florida, *in* Proceedings of the 17th Annual National Meeting, American Society for Surface Mining and Reclamation, Tampa, Fla., June 11-15, 2000, p. 197-204.

Chapter 11: Postplanting Control of Undesirable Vegetation

Bottomland hardwood forests have an abundance of naturally occurring woody and herbaceous plants that may be regarded as undesirable in a restoration project, especially in the early stages when they might affect the survival and growth of planted trees. Also, exotic species are very well established in all areas covered by this guide. In southern Illinois, for example, early stages of succession on old-field sites used to be dominated by native broomsedge, smooth and winged sumac, sassafras, and common persimmon. Now, similar sites might be dominated by sericea lespedeza, Chinese bushclover, Japanese honeysuckle, multiflora rose, and autumn olive, all of which are exotics.

Control of undesirable plant species is typically only needed in the first few years of a restoration project, after which the planted vegetation should be large enough to compete on its own. Control can be achieved manually, with machines, or with herbicides.

Although an intensive program of postplanting weed control may substantially increase survival and growth of planted stock, control should be employed sparingly. Weed control will reduce the initial value of a restoration site for small mammals and bird species that use the weeds as food and cover. Also, these weeds may be promoting forest development by contributing humus to the soil and partial shade to forest tree seedlings.

Another reason to use postplanting weed control sparingly is that the long-term benefits may not justify the costs. In some experiments where a significant growth enhancement with weed control was found over the first 5 to 10 years, the effect virtually disappeared after a few more years.

Manual Vegetation Control

Vegetation control using hand tools such as hoes, axes, brushhooks, and machetes has the potential advantage of being highly selective in what is removed (fig. 11.1). A disadvantage of manual methods is that they usually result in a very temporary form of control; unless the undesirable plants are being uprooted, they are likely to resprout quickly. Because the labor forces employed for weeding are likely to be relatively inexperienced, there is also a high probability of injury to workers and inadvertent damage to desired species.

Manual weed control may be best employed on small projects or as a supplement to other forms of weed control on larger projects. It also may be the safest method to use to remove vines from young hardwood trees because the vines grow too close to the tree to be removed by cultivation, and herbicide applications may also damage the tree.

Figure 11.1. Manual vine control can be accomplished using brushhooks or machetes.

Mechanical Vegetation Control

Mechanical weed control is widely used in commercial forestry operations and has proven to be highly effective on bottomland sites. A disadvantage of mechanical weed control is that it is difficult to employ if the trees are not planted in rows. Other disadvantages are the high equipment costs and energy consumption.

Cultivation should begin early in the first growing season (March or April) and may need to be repeated as many as three to four times during the first year. Supplementary hand weeding may also be needed to control vines that are too close to planted trees to be removed mechanically. There are many types of equipment available for cultivating bottomland hardwoods, but most foresters prefer tractors of about 110 horsepower. Tractors of this size are small enough for cultivating between rows but also large enough for other jobs such as clearing, disking, and planting.

Front-mounted cultivators allow the driver to have better visibility and control than rear-mounted cultivators, resulting in less damage to planted trees. Cultivators equipped with chisel- or shovel-type plows allow tillage close to the young trees but do not damage them appreciably. Two types of cultivators are most frequently used. One is a large, front-mounted cultivator with 19 to 21 shanks that will straddle one row while covering the space within the rows. The second type is an offset front-mounted cultivator equipped with five or six shanks that straddle the row while covering a small area on each side; with this system, a disk or spring-tooth harrow drawn behind the tractor covers the area between rows.

The unit in a cultivation operation therefore consists of a tractor plus either a large cultivator or a small cultivator with a disk or harrow (fig. 11.2). When the trees become too tall to straddle, the cultivators are removed and tillage between rows is accomplished with just a disk or harrow.

To ensure the best results from cultivation and to minimize tree damage and equipment breakage, the restoration site should be as free as possible from stumps, large roots, and other debris. The cultivator shanks that straddle the trees should be set to plow 8-10 cm (3-4 inches) deep to within 8-10 cm (3-4 inches) on each side of the tree. The area between rows should be plowed to a depth of 10-15 cm (4-6 inches). Cultivation to these depths will probably cut some of the roots that lie in the top 20 cm (8 inches) of soil, but some researchers believe that cutting causes root proliferation and is therefore beneficial because it increases the absorptive surface.

Disking patterns should be alternated during cultivation; that is, a row cultivated in, say, a north-south direction during the first trip down a row should be cultivated south-north during the next trip. If tandem disks are used, the front blades should be set to throw soil toward the trees and the rear ones to throw soil away from the trees. The disk blades should be about 50-60 cm (20 to 24 inches) in diameter. The width of the disk or harrow would be determined by tree spacing but would be 0.6-0.9 m (2-3 ft) narrower than the spacing to allow plowing to within 30-45 cm (12-18 inches) of the trees.

Cultivation should be postponed during wet weather to avoid soil compaction, damage to tree roots, and equipment damage.

Figure 11.2. Mechanical cultivation of a restoration site.

Vegetation Control with Herbicides

The many different herbicides and herbicide application methods available for use on restoration projects are continuously evolving. It is important to refer to the most up-to-date sources of information on such issues as personal and environmental safety and relevant State and Federal regulations. Recent sources of information on herbicides for forestry and agricultural use are cited at the end of this chapter, but keep in mind that little research on the appropriate herbicides for use in bottomland hardwood sites has been conducted (but see Miller, 1993 and Ezell and Catchot, 1998). When herbicide use is planned, a combination of proper herbicide prescriptions, technically sound applications, and a commitment to minimizing negative impacts to the environment are the keys to successful use.

Table 11.1 lists some of the most commonly used herbicides for control of herbaceous and broad-leaved (woody) vegetation. This table is meant to serve as an initial source of information on herbicides, not as the final basis for herbicide selection and does not constitute an endorsement of any of the herbicides listed. Also, not all these herbicides are labeled for herbaceous or woody vegetation control in all states.

The weed species controlled by specific herbicides should be investigated thoroughly before making the final selection(s) for use on a particular project. Information such as that presented in table 11.2 is available for most herbicides and should be referred to once the restorationist knows which weeds are most in need of control.

The optimum timing for herbicide applications varies with the type of weeds being controlled and the particular herbicide and application method being used. Guidance on timing for some of the most common herbicides used in commercial forestry operations is presented in fig. 11.3.

Since weed control should be used very sparingly on most restoration projects, only the most selective application methods are recommended. To control herbaceous vegetation around individual planted trees, backpack or hand-held sprayers (fig. 11.4) are very effective. To control undesirable woody species, tree injectors, hypohatchets, hatchet and spray bottle combinations, or spot guns are recommended.

Selected References

Cantrell, R.L., ed., 1985, A guide to silvicultural herbicide use in the southern United States: Auburn University, Ala., Alabama Agricultural Experiment Station, 592 p.

Ezell, A.W., 1995, Importance of early season competition control in establishing eastern cottonwood (*Populus deltoides*) plantations, *in* Edwards, M.B., ed., Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, November 1-3, 1994, Auburn, Ala.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-1, p. 94-97.

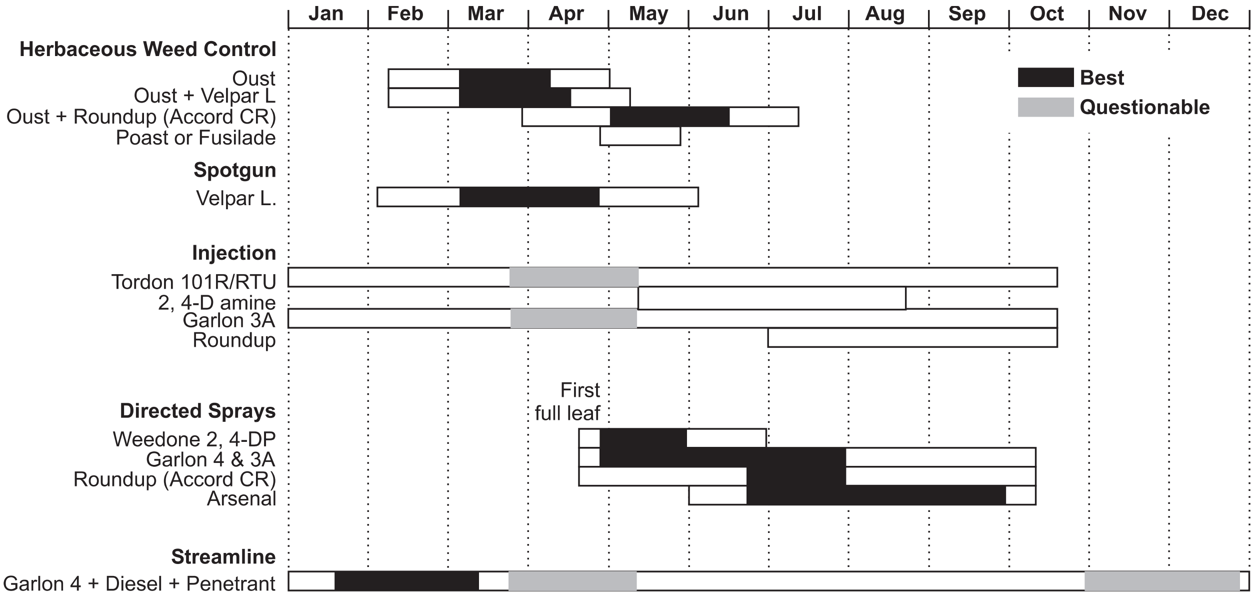
Ezell, A.W., and Catchot, A.L., Jr., 1998, Competition control for hardwood plantation establishment, *in*

Table 11.1. Commonly used herbicides (adapted from Mitchell and Lowery, 1994).

Common Name	Trade Name	Use
Atrazine	Atrazine 4L	Herbaceous
	AAtrex 4L	Herbaceous
	AAtrex 80W	Herbaceous
	AAtrex Nine-O	Herbaceous
Dicamba	Banvel CST	Broad-leaved
Dicamba + 2,4,D	Banvel 720	Broad-leaved
Fluazifop-butyl	Fusilade 2000	Herbaceous
Glyphosate	Accord CR	Herbaceous
	Roundup	Herbaceous
Hexazinone	Pronone 5G	Herbaceous
	Velpar L	Herbaceous
Imazapyr	Arsenal Applicator Concentrate	Herbaceous
Oxyfluorfen	Goal	Herbaceous
Picloram + 2,4-D	Tordon	Broad-leaved
Sethoxydim	Poast	Herbaceous
Sulfometuron methyl	Oust	Herbaceous
Triclopyr	Garlon 3A	Broad-leaved
Triclpoyr + Butoxyethyl ester	Garlon 4	Broad-leaved
2,4-D	Weedone 2,4,DP	Broad-leaved

Table 11.2. Weed species susceptible to Oust (Mitchell and Lowery, 1994).

Susceptible	Moderate	Tolerant
Controlled by 3 oz/acre	Controlled by 5 oz/acre	Not controlled
Panic grasses	Goldenrod	Bermuda grass
Fescue	Dogfennel	Morning glory
Horseweed	Bahia grass	Broomsedge
Burnweed	Johnson grass	Wooly croton
Boneset		Trumpet creeper
Ragweed		Sicklepod
Sunflower		Cocklebur
Poorjoe		Nutsedge
Dewberry		
Vetch		
Geranium		
Goldenweed		
Sweet clover		
Crabgrass		



Dates are approximate for the upper coastal plains. Spring dates will shift plains to the mountains because of earlier frost.

Figure 11.3. Guidance on the timing of herbicide applications in commercial forestry (modified from Miller and Bishop, 1989).

Figure 11.4. Herbicide application with a backpack sprayer.

Waldrop, T.A., ed., Proceedings of the Ninth Biennial Southern Silvicultural Research Conference, February 25-27, 1997, Clemson, S.C.: Asheville, N.C., U.S. Department of Agriculture, Forest Service, General Technical Report SRS-20, p. 42-43.

Hamel, D.R., 1983, Forest management chemicals, Agricultural Handbook 585: Washington, D.C., U.S. Department of Agriculture, Forest Service, 645 p.

Kennedy, H.E., Jr., 1981, Bottomland hardwood research on site preparation, plantation establishment, and cultural treatments at the Southern Hardwoods Laboratory, *in* Barnett, J.P., ed., Proceedings of the First Biennial Southern Silvicultural Research Conference, November 6-7, 1980, Atlanta, Ga.: New Orleans, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, General Technical Report SO-34, p. 75-78.

Kennedy, H.E., Jr., and Henderson, W.H., 1976, Cultivation in cottonwood plantations—practice and equipment, *in* Thielges, B.A., and Land, S.B., Jr., eds., Proceedings of the Symposium on Eastern Cottonwood and Related Species, September 28 - October 2, 1976, Greenville, Miss.: Baton Rouge, La., Louisiana State University, Division of Continuing Education, p. 379-384.

Miller, J.H., 1989, Optimum timing for ground-applied forestry herbicides in the South: Atlanta, Ga., U.S. Department of Agriculture, Forest Service Management Bulletin R8-MB 28.

Miller, J.H., 1993, Oak plantation establishment using mechanical, burning, and herbicide treatments, *in* Loftis, D.L., and McGee, C.E., eds., Oak regeneration: serious problems, practical recommendations: U.S. Department of Agriculture, Forest Service, SEFES Publication GTR SE-84, p. 264-289.

Miller, J.H., and Bishop, L.M., 1989, Optimum timing for ground-applied forestry herbicides in the south: Atlanta, Ga., U.S. Department of Agriculture, Forest Service Management Bulletin R8-MB 28.

Miller, J.H., and Mitchell, R.J., eds., 1994, A manual on ground applications of forestry herbicides: Atlanta, Ga., U.S. Department of Agriculture, Forest Service Management Bulletin R8-MB 21. [Orientation is towards commercial pine production but still contains much useful information on application methods, safety, pertinent laws, and specific herbicides.]

Mitchell, R.J., and Lowery, R.F., 1994, Herbaceous weed control in young pine plantations, *in* Miller, J.H., and Mitchell, R.J., eds., A manual on ground applications of forestry herbicides: Atlanta, Ga., U.S. Department of Agriculture, Forest Service Management Bulletin R8-MB 21 (revised), p. 4-1 to 4-8.

Rhodenbaugh, E.J., and Yeiser, J.L., 1994, Hardwood seedling tolerance to selected Oust® treatments: Proceedings of the Southern Weed Science Society Annual Meeting, v. 47, p. 98-103.

Chapter 12: Protection of the Restoration Site

Restoration projects can be damaged or destroyed by a variety of agents, ranging from depredation by herbivores to vandalism. To the degree possible, the needs for protection from these agents should be anticipated in the site evaluation stage, and plans should be drawn up for implementing protective measures.

Protection from Animals

Herbivores (and the occasional omnivore) can seriously damage or destroy planted seed or seedlings. The most frequent offenders are deer, raccoons, squirrels, beaver, nutria, and small rodents. In some cases, cattle, hogs, or birds may cause damage.

One of the best forms of protection against the smaller rodents is to plant seed or seedlings on a relatively weed-free site, since this minimizes the amount of cover available to protect rodents from predation. Usually by the time the weeds provide enough cover for small rodents, the seedlings are relatively safe; however, if there is evidence of damage to seedlings (e.g., girdling, clipped twigs), it is advisable to carry out some postplanting weed control.

Protection of some planted sites can be achieved by controlling water levels, but specific guidelines for use of this technique are not available. For example, water tolerant species can be temporarily flooded to protect them from small rodents, or in the case of beaver and nutria, the site can be kept drained until the seedlings are well established. In large open fields, provision of perches for raptors may be an effective strategy for reducing rodent populations.

More direct forms of control may be necessary in cases where animal populations are particularly high and/or cover cannot be reduced adequately by other means. These forms of control, however, should only be employed as a last resort, especially near populated areas and on public lands. Traps or poison can be used to temporarily reduce populations of small rodents. Larger animals can also be shot. For instance, shooting nutria or beaver can be a very effective means of short-term control; one technique is to go out at night with a light and use a .22 rifle (which is fairly quiet). The only practical direct control measure for deer is an either-sex harvest in conjunction with state hunting seasons, which is obviously out of the control of most restorationists.

Fencing the site will protect it from cattle and hog damage. Fencing may also provide protection from beaver and nutria, although these animals, especially nutria, may be able to burrow under or even climb over a fence. Fencing will only work well if it is done right (using good quality fencing material and sturdy, metal or treated wooden posts) and if it is periodically inspected and maintained.

Individual seedlings can be protected by using either wire predator guards or plastic tree shelters (fig. 12.1a,b), but costs can be prohibitive on large projects.

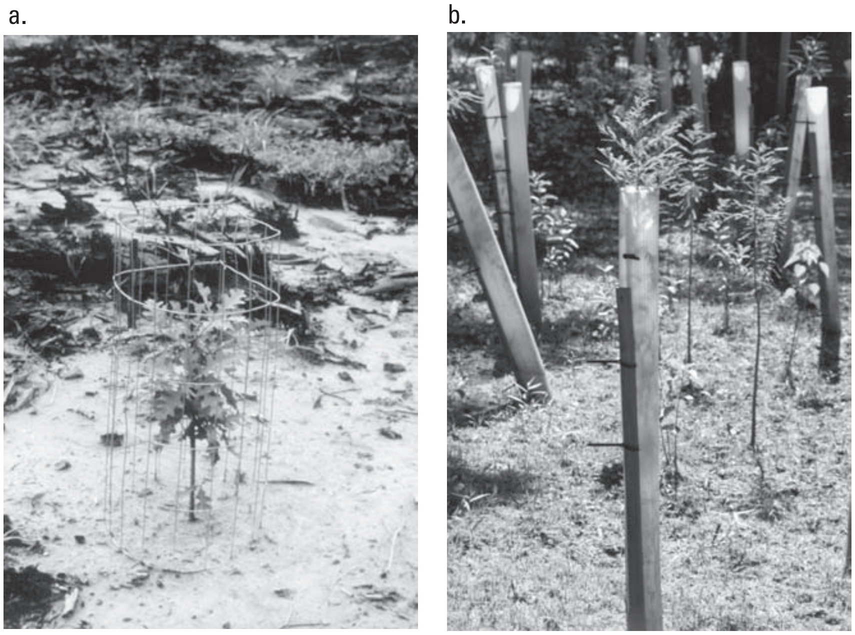

a.
b.

Figure 12.1. Herbivory protection by (a) wire predator guard and (b) plastic tree shelter.

Tree shelters have the additional advantages of enhancing growth and making it easier to safely apply herbicides around the base of individual seedlings. While generally effective, neither wire guards nor tree shelters can ensure complete protection in cases where animal populations are high and alternative food sources are low. For example, both methods have occasionally failed to protect newly planted baldcypress seedlings from nutria, which have burrowed under, climbed over, knocked over, and chewed through these protectors. In extreme cases, these wire guards or tree shelters should be used in conjunction with direct population control measures.

Protection from Fire

Although most bottomland hardwood sites are wet throughout much of the year, they do occasionally dry out, and there are several instances in which restoration sites have been damaged by fire. The best protection is to make a firebreak around the site, usually by disking (see fig. 5.1). Firebreaks should be periodically inspected and maintained, particularly before and during periods of peak fire danger. Firebreaks are particularly important in areas where prescribed fire is frequently used or where the restoration site is close to a heavily traveled road.

In peninsular Florida and in the northern Gulf of Mexico Coast the rapid spread of cogongrass, an exotic species, has created a fire hazard. This species burns readily and can spread and intensify a fire rapidly. Heavy applications of herbicides are being made to eliminate this grass as it appears in bottomland hardwood creation sites on mined lands. As cogongrass continues to spread, its threat of carrying fires could increase substantially in the next few years.

Protection from Human Impacts

In most areas, restoration sites are subject to some damage from humans, be it intentional or unintentional. Fencing and “No Trespassing” signs may prove necessary in areas that could be used by off-road recreational vehicles, play areas for children, or places to dump trash and yard wastes. Informing nearby residents of the project and/or putting an informative sign about the project on the site (fig. 12.2) may also help reduce damage.

Figure 12.2. An informative sign such as this can provide useful information to individuals using or visiting the site.

In agricultural areas, some restoration sites have been damaged or destroyed by farm machinery or aerial drift from nearby herbicide applications. Farmers on adjacent land should be informed about restoration sites on which they might potentially have an impact.

In urban areas, plants have actually been stolen from some restoration sites. This is most likely to happen when larger, high-value planting stock has been used, such as tree seedlings that were in 1-gallon or larger size containers. Sites where theft is a possibility should be protected by fencing. In some cases armed guards have been employed to protect restoration sites. Where theft or vandalism is likely to be a problem, it may be desirable to use smaller, less conspicuous (and less valuable) planting stock.

Selected References

Allen, J.A., and Boykin, R., 1991, Tree shelters help protect seedlings from nutria (Louisiana): Restoration and Management Notes, v. 9, no. 2, p. 122-123.

Clewell, A.F., and Lea, R., 1990, Creation and restoration of forested wetland vegetation in the southeastern United States, *in* Kusler, J.A., and Kentula, M.E, eds., Wetland creation and restoration: the status of the science: Washington, D.C., Island Press, p. 195-231.

Chapter 13: Monitoring

Monitoring is an important element in any properly conducted restoration project. Too often, however, restoration projects are put in place and monitored poorly if at all. Failure to follow up on a project obviously results in a lack of information on how well the project is succeeding in meeting its objectives. Success criteria (as discussed in Chapter 2) can only be evaluated through a program of monitoring. The lack of monitoring also eliminates the chance for promptly carrying out post-planting corrective measures (midcourse corrections) that may save a project. Furthermore, the failure to monitor projects may result in repeating mistakes in future projects.

Monitoring does not always have to be sophisticated and expensive to be effective. Simply walking through a restoration site may be enough to spot some problem that needs to be remedied, such as excessive weed competition, damage to a fence, herbivory problems, or a malfunctioning water control structure. To be most effective, this type of monitoring should be done frequently at first (at least monthly), especially if extensive earthmoving or hydrologic modifications were done, or the site is an area subject to human disturbance.

When designing a monitoring program involving the collection of quantitative information, five things should be considered carefully: (1) what is the purpose of the monitoring program? (goals which are tied directly to success criteria should be specified), (2) what are the most appropriate methods for achieving the goals? (3) how should the data be handled and analyzed? (4) how will the data be interpreted (and who will do the interpretation)? and (5) when will the monitoring program achieve its goals and be terminated? Two guiding principles should be to keep the program as simple as possible and to collect data only if it meets a specific need and addresses a specific success criterion. It should also be kept in mind that because of the relatively long-term nature of many monitoring projects, personnel will change over time. Good records should therefore be kept on all aspects of the program, including sampling protocols, plot locations, and information on how and where data are stored.

Vegetation Monitoring

A wide range of techniques developed by plant ecologists and foresters is available for use in vegetation monitoring. Most of these techniques are based on the sampling of vegetation along transects and/or in plots. Some of the most commonly used measures of vegetation abundance or plant performance are summarized in table 13.1. In general, an effective monitoring program will use a combination of absolute measures of abundance and selected measures of performance.

If transects or plots are used, they should be permanently marked because remeasuring the same area each time will provide information on trends in survival and plant performance. Sections of PVC pipe placed at either end of transects or in plot centers works well in most cases, especially where vandalism is not a major problem. Plots and transects should also be located in a truly random or systematic fashion, not selected subjectively.

One example of a simple, inexpensive, and yet appropriate monitoring system is that used by the Louisiana Department of Wildlife and Fisheries to evaluate the survival of their direct-seeded reforestation sites. They establish 50-ft (15.2 m) transects along every third row at the time of planting. The transects are marked with five flags; some of the flags are tagged in such a way that the exact position of the transect can be relocated if one or more flags are lost. The transects are established so they stretch out either diagonally across the field (fig. 13.1) or in another arrangement that captures the variability of topography within the field. In late summer and again 2 or 3 months later, at the end of the first growing season, the seedlings along these transects are counted. If the average number of seedlings per transect is below the target of three, then the field may be replanted. Since the only stated goal of these restoration projects is reestablishment of the hard mast producing species that were actually planted, there is no need for more extensive monitoring. The decision to replant a site should only be made after consideration of the fact that many seedlings may be difficult to see (hidden by herbaceous vegetation, delayed germination of direct-seeded acorns, clipped by rodents but retaining living roots, etc.). It is usually advisable to wait until at least 3 to 5 years post planting before evaluating seedling survival and stocking rates.

An example of a somewhat more complicated and expensive vegetation monitoring system is that used by Agrico Chemical Company on their Morrow Swamp restoration site in central Florida. They established a system of 12 permanent belt transects (elongated quadrats) that are 29.5 ft (9 m) in width and from 300 to 900 ft (90-275 m) in length (fig. 13.2). All trees were measured for height and crown diameter and classified into one of seven categories based on the tree's condition (live, stressed, tip dieback, basal sprouts, apparently dead, dead, and missing). The transects are measured annually, and the data are summarized in a series of tables and graphs (fig. 13.3).

Where reference wetlands have been used as a guide for designing the restoration project, various indices can be employed to compare the reference and restoration

Table 13.1. Measures of vegetation abundance and plant performance that can be used for monitoring.

Abundance measures	Description
Presence or absence of vegetation	This is a simple list of what species are present without more specific information on abundance.
Presence or absence of vegetation combined with frequency estimates	In addition to listing species present, an estimate of frequency (e.g., common, occasional, rare) is made. Simple, but relatively imprecise.
Absolute measures	
Density	Number of individuals per unit area. Easy to use with trees but difficult with herbaceous plants.
Cover	Proportion of ground covered by a species (should be envisioned as a vertical projection of the species to the ground). Often estimated by eye, although this can be inaccurate, and results will vary from worker to worker.
Biomass/yield	Usually involves destructive sampling of plots to obtain dry weight estimates for each species. Cannot be recommended for restoration projects unless samples are small or biomass/yield can be accurately estimated from variables such as plant height and diameter.
Basal area	Cross-sectional area of each species per unit area (e.g., ft^2/acre). Widely used for tree and shrub species.
Nonabsolute measure	
Frequency	The proportion of plots containing a particular species. Simple, but results may vary with plot size and sampling intensity.
Measures of plant performance	
Growth	Most commonly defined as height or diameter growth.
Mast/seed production	Could include proportion of individuals producing seed and/or a quantitative measure of seed production (i.e., yield).
Indicators of plant health or damage	Possible indicators include evidence of branch dieback, defoliation, nutrient stress, and fire or browsing damage.

sites. These include simple tallies of the number of species on each site (species richness) and more complex diversity and similarity indices. Index values should be evaluated with caution, however. High species richness or diversity, for example, may be due to the presence of weeds and undesirable exotic species. It is therefore advisable to limit some index comparisons to those preferred species that are typical of mature, undisturbed forest. Also, such indices are of limited use for most restoration projects because of the large differences that naturally occur between forests in early successional stages (the project site) and mature forests (the reference sites).

Hydrologic Monitoring

On restoration sites with minimal disturbance, qualitative monitoring of hydrology may be adequate. Hydrologic monitoring could involve visiting the site during seasons when flooding or saturated soils are expected to occur, or inspecting the site at other times for evidence that the hydrology is adequate (e.g., drift lines, sediment deposited on leaves, water lines on trees).

The use of quantitative monitoring techniques is worthwhile for projects on heavily disturbed sites. Staff gages, piezometers, and shallow monitoring wells (fig. 13.4) can be used for measuring water table levels and/or groundwater flow directions. Staff gages provide a measure of standing water above the soil surface. They are inexpensive, easy to install, and easy to read. Piezometers, which are screened for water entry (and sediment exclusion) only near their bottom end, are used to measure the potentiometric surface, which is not necessarily the same as water table level. These data are used to determine groundwater flow directions and water levels (pressures) below a confining layer in the soil. Piezometers are especially useful for monitoring contaminant movement (Freeze and Cherry, 1979). Shallow monitoring wells are screened along most of their length and are useful for measuring the water table depth in soils without a confining layer. Great care must be exercised

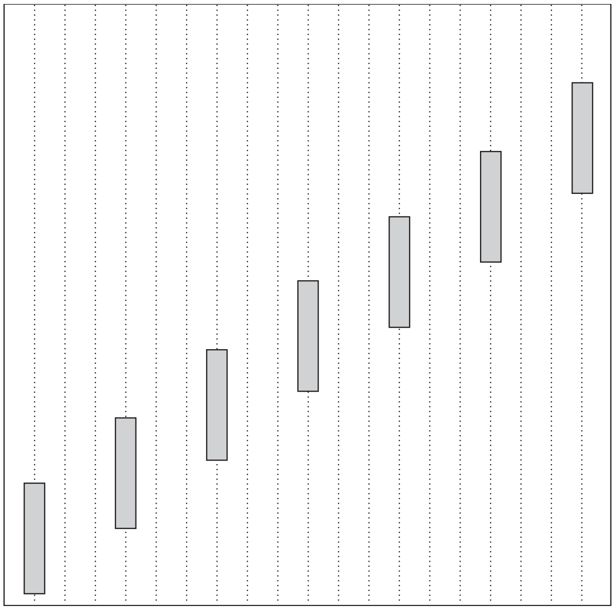


Figure 13.1. Diagonal layout of sample transects across a direct-seeded field.

in the installation of monitoring wells (Sprecher, 1993). If a well is installed through a confining layer, such as a clay layer, water may be able to flow through the well casing from a perched aquifer above the confining layer into a lower layer below the clay, resulting in bad data and possible damage to the local wetland.

Staff gages, piezometers, and monitoring wells should be distributed to cover the range of hydrologic variability within the restoration site. As an example, figure 13.5 shows the placement of piezometers and staff gages on a phosphate mine reclamation site in Florida. Readings of these gages and wells should be taken on at least a monthly basis for the first year of most projects. The actual measurement interval will depend on the hydrologic regime, soil type, topography, and type of study.

In some cases periodic water level measurements may be inadequate, and more frequent monitoring will be necessary. Several methods are available to provide continuous measurements of above- or belowground water levels. Chart type water level recorders have been used extensively in the past. These recorders typically use a chain/cable and weight attached to a float in a stilling well. As the float moves up and down with water levels, a chart is rotated under a pen and water levels are recorded on the scaled chart. The main shortcoming of these types of recorders is that they are relatively expensive and can only measure one variable (water level) at one location. Another disadvantage is that the data on the chart must be read and recorded separately, adding another step and delay in making the data available. Updated (and more expensive) versions of these recorders that log the measurements electronically are also available.

More recently, dataloggers have been used extensively for recording water levels and numerous other variables, such as wind direction and speed, total solar radiation and/or photosynthetically active radiation, temperature of the air, soil or water, relative humidity, precipitation, etc. A good quality datalogger can be obtained for about the same price as a chart type recorder, but individual probes push the cost somewhat higher. Although some probes such as air/water/soil temperature probes are inexpensive at about $70 each, other probes such as commercially available water level sensors can be quite expensive at about $600 each. Inexpensive water level sensors can, however, be constructed using readily available materials for about $60 or less each (Keeland and others, 1997).

Many researchers have started using single purpose water level recorders, such as the WL-40 or WL-80 manufactured by Remote Data Systems (fig. 13.6).

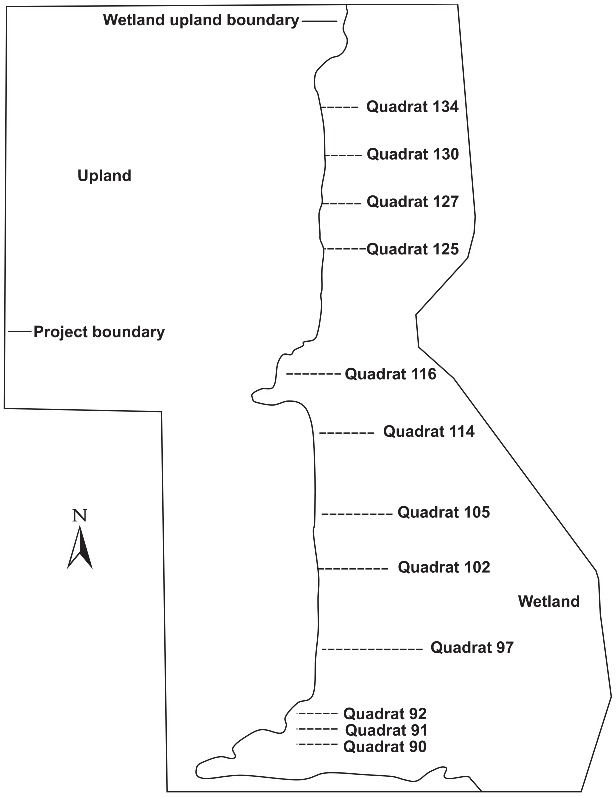


Figure 13.2. Location of forest reclamation strip quadrats at the Morrow Swamp (Agrico Swamp West) restoration site (from Kevin L. Erwin, Consulting Ecologist, Inc., 1990).

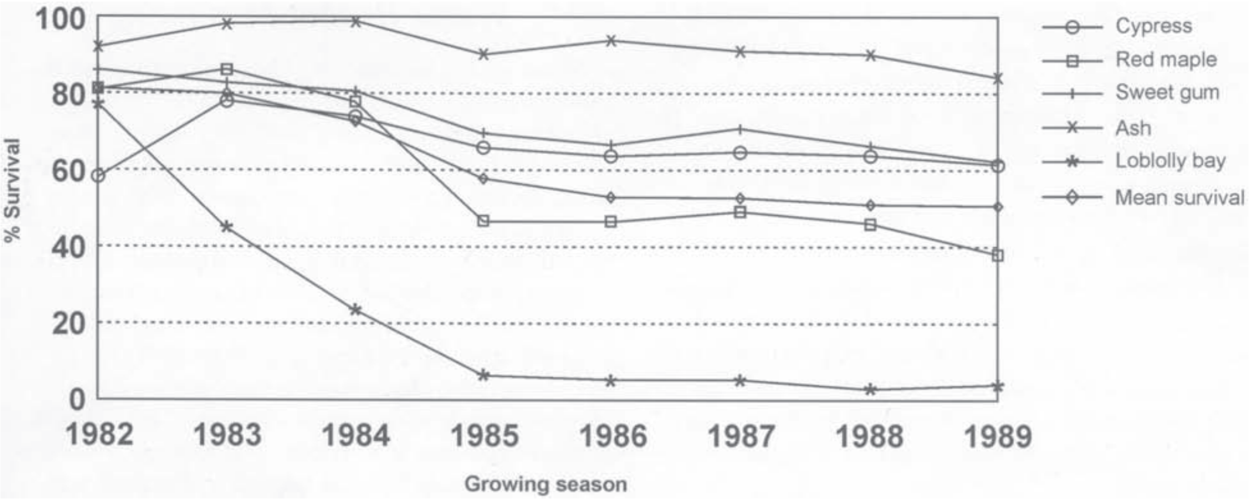


Figure 13.3. Tree survival trends at Morrow Swamp (Agrico Swamp West) restoration site (from Kevin L. Erwin, Consulting Ecologist, Inc., 1990).

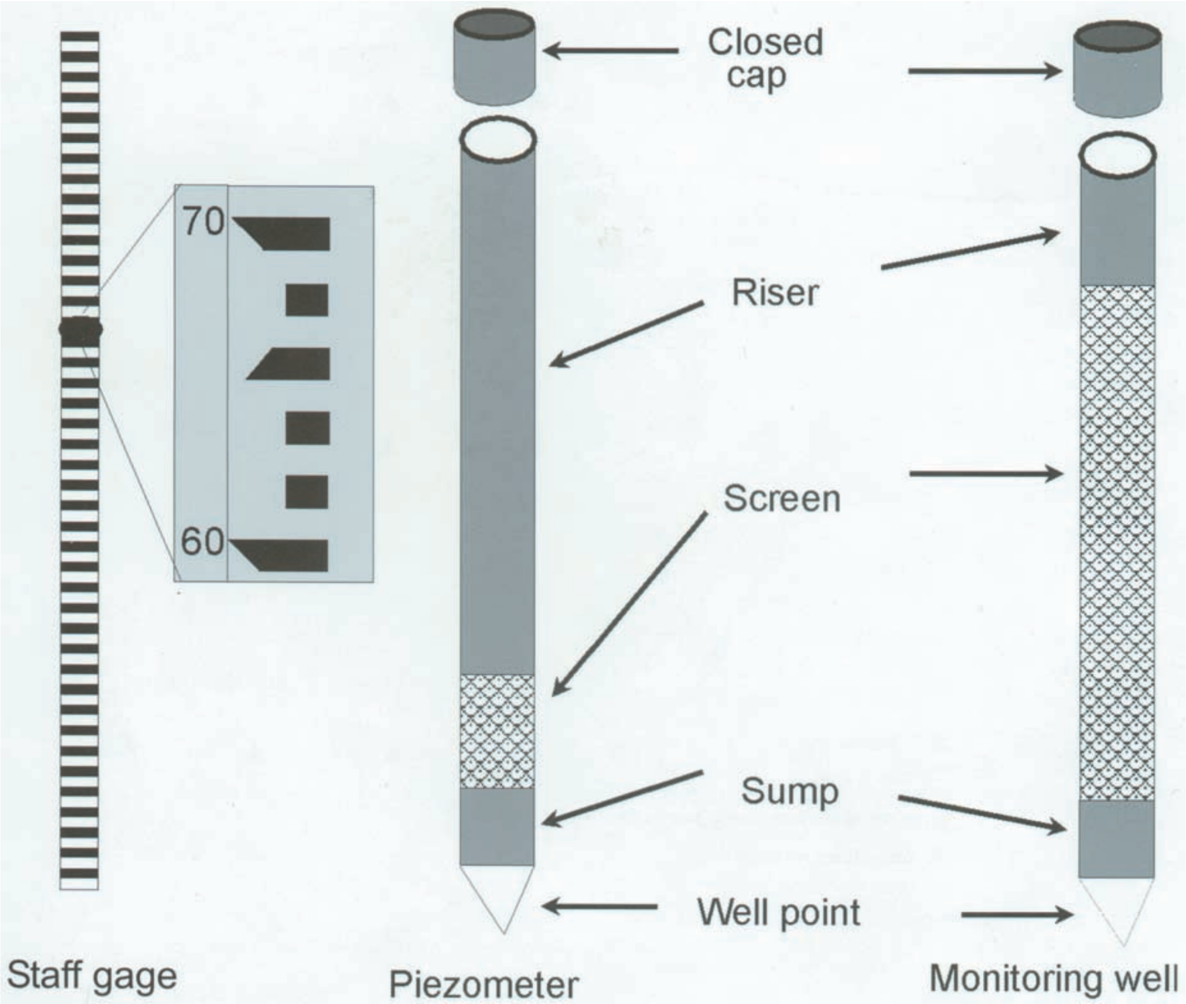


Figure 13.4. Staff gages, piezometers, and monitoring wells can be used to determine the pattern of flooding (hydrologic regime) of a restoration site. Such piezometers and wells can be purchased commercially or made from PVC pipe.

An advantage of these instruments is the ease of data downloading, which is accomplished with a hand held calculator using an infrared-light communications pathway. The instruments can be easily camouflaged (do not use paint for camouflage as it may block the water entry pathways) in field situations where tampering may be likely. A disadvantage is that they only work over a limited range (1 or 2 m - 40 or 80 inches) and are almost as expensive as the chart type recorders or more capable dataloggers which work over a much wider range of water levels. In areas with a limited range of water level fluctuations, single purpose water level recorders are probably the instrument of choice, but in riverine sites where water levels fluctuate more than 2 m, they may not be adequate.

Water Quality Monitoring

Water quality monitoring of bottomland hardwood restoration projects may be required to demonstrate compliance with state water quality regulations; otherwise, monitoring will be useful primarily in those cases where specific problems are anticipated. Examples of water quality parameters that may be measured include pH, alkalinity, dissolved oxygen, nitrogen, phosphorus, turbidity, suspended solids, total organic carbon, presence of heavy metals, water temperature, redox potential, specific conductance and/or salinity, etc.

Considerations for a water quality monitoring program include measurement protocols (these should generally conform to Environmental Protection Agency standards), sample size and frequency, distribution of

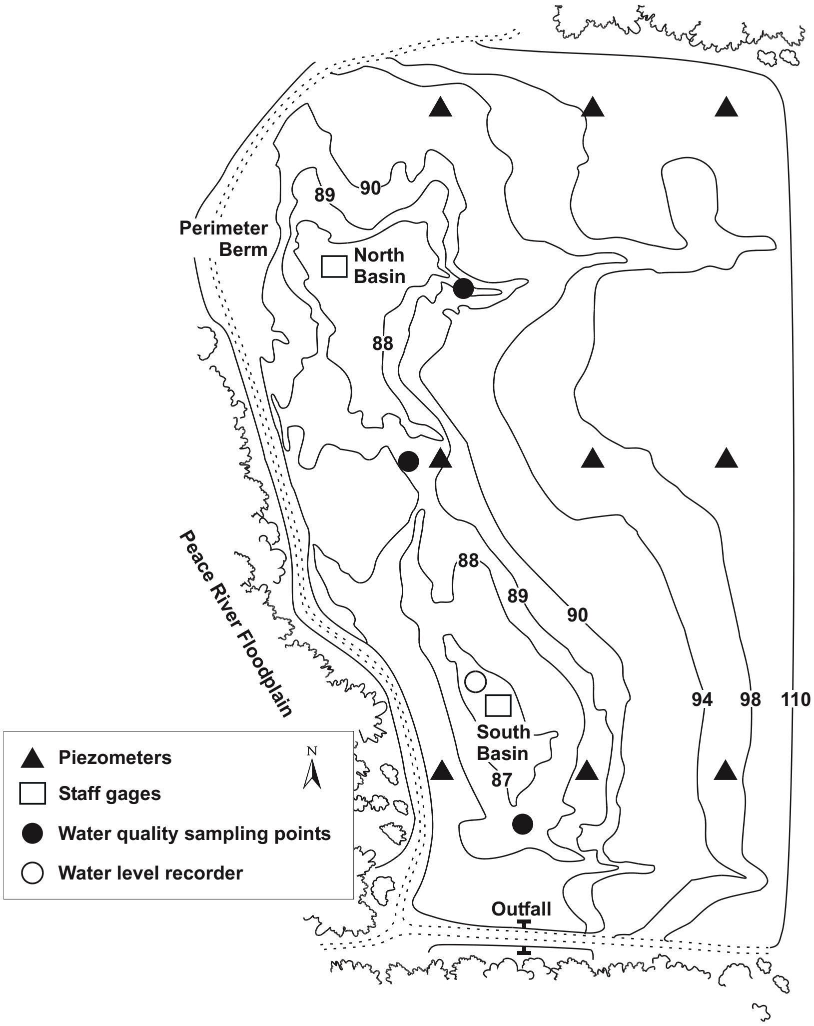


Figure 13.5. Placement of piezometers and staff gages on a reclaimed phosphate site in Florida (from Kevin L. Erwin, Consulting Ecologist Inc., 1990).

Figure 13.6. Example of an automated, single purpose water level recorder, the WL-80 being downloaded. The WL-80 (arrow) is mounted next to the stilling well of a Stevens type recorder. Inset shows the head of the WL-80 and the calculator used for downloading.

sampling stations, and the availability of a suitable site for comparison (i.e., a reference site or a suitable upstream location). The MiST document (White and others, 1990) suggests that at a minimum, 24 sets of samples from surface water and groundwater be taken on a monthly basis from both the restoration site and a reference site for the first 2 years of the project (see table 2.1). Other monitoring programs, such as the Agrico phosphate mine site in Florida, have sampled water quality on a quarterly basis.

In addition to regular sampling, it may be desirable to sample water quality during unusual conditions, such as peak floods and low water events. Water quality conditions during these times may be a controlling influence on the overall success of the wetland restoration project.

Soils Monitoring

On sites with minimal soil disturbance, such as old-field sites, very little soil monitoring is necessary, especially if the project is not being conducted as mitigation for a specific development project. It might be worthwhile, however, to inspect the site and determine if one or more of the field indicators of hydric soils described in the U.S. Army Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory, 1987) are present. These field indicators include presence of organic soils; histic epipedons; sulfidic material; an aquic or peraquic moisture regime; direct evidence of reducing conditions; gleyed, low chroma and low chroma/mottled soils; and iron and manganese concretions. The delineation manual provides additional indicators of wetland hydrology for special soils, such as highly sandy soils or soils with spodic horizons.

On heavily disturbed sites, bulk density, soil pH, nutrient status, organic matter, and in some cases, redox potential or specific phytotoxin levels need to be assessed. Measurement of soil macroinvertebrates and microorganisms may also be worthwhile, especially when compared to an appropriate reference wetland, since the biomass and species composition of these communities are two of the best indicators of whether a soil is functioning as desired.

Wildlife Monitoring

Monitoring the wildlife use of restored bottomland forests is in some ways more difficult than monitoring vegetation, hydrology, and soils. For one thing, many animal species are secretive, and it may therefore be very difficult to determine whether they are using the restoration site. A more fundamental problem is that many years must pass before an adequate evaluation can be made if the goal is to provide habitat for wildlife that use mature forest habitat.

One way to address the difficulties of monitoring wildlife is to characterize use of the site by common, relatively conspicuous (or easily trapped) species that use forested wetlands in early stages of succession. Table 13.2 lists some wildlife species that use forested wetland sites in the early stages of forest development, from open fields or forest gaps to a stage just before crown closure. More extensive lists of expected species could be developed for particular project sites and compared with the species actually found on the site.

Where direct monitoring is employed, techniques will vary depending on the species being sought and whether the goal is simply to determine presence or absence (qualitative monitoring) or approximate numbers of individuals present (quantitative monitoring). Another

Table 13.2. Wildlife species that use early successional stages of bottomland hardwood forested wetlands (order of species, common names, and scientific names follows Banks and others, 1987).

Common Name	Scientific Name
Amphibians	
Eastern newt	*Notophthalmus viridescens*
Flatwoods salamander	*Ambystoma cingulatum*
Eastern tiger salamander	*Ambystoma tigrinum*
Southern dusky salmander	*Desmognathus auriculatus*
Two-lined salamander	*Eurycea bislineata*
Dwarf salamander	*Eurycea quadridigitata*
Mud salamander	*Pseudotriton montanus*
Many-lined salamander	*Stereochilus marginatus*
Greenhouse frog	*Eleutherodactylus planirostris*
Bird-voiced tree frog	*Hyla avivoca*
Pine woods treefrog	*Hyla femoralis*
Squirrel treefrog	*Hyla squirella*
Gray treefrog	*Hyla versicolor*
Ornate chorus frog	*Pseudacris ornata*
Striped chorus frog	*Pseudacris triseriata*
Wood frog	*Rana sylvatica*
Reptiles	
Common mud turtle	*Kinosternon subrubrum*
Snapping turtle	*Chelydra serpentina*
Painted turtle	*Chrysemys picta*
Diamondback terrapin	*Malaclemys terrapin*
Eastern fence lizard	*Sceloporus undulatus*
Eastern glass lizard	*Ophisaurus ventralis*
Ground skink	*Scincella lateralis*
Eastern indigo snake	*Drymarchon corais couperi*
Black rat snake	*Elaphe obsoleta*
Yellow rat snake	*Elaphe obsoleta quadrivittata*
Green rat snake	*Elaphe triaspis*
Eastern mud snake	*Farancia abacura*
Rainbow snake	*Farancia erythrogramma erythrogramma*
Common kingsnake	*Lampropeltis getulus*
Plain-bellied water snake	*Nerodia erythrogaster*
Gopher snake	*Pituophis melanoleucus*
Pine woods snake	*Rhadinaea flavilata*
Midland brown snake	*Storeria delayi wrightorum*
Eastern ribbon snake	*Thamnophis sauritus*
Common garter snake	*Thamnophis sirtalis*
Southern copperhead	*Agkistrodon contortrix contortrix*
Eastern cottonmouth	*Agkistrodon piscivorus piscivorus*
Birds	
Great blue heron	*Ardea herodias*
Green-backed heron	*Butorides striatus*
Great egret	*Casmerodius albus*
Yellow-crowned night heron	*Nycticorax violaceus*
Wood stork	*Mycteria americana*
Wood duck	*Aix sponsa*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Red-tailed hawk	*Buteo jamaicensis*
American swallow-tailed kite	*Elanoides forficatus*
American kestrel	*Falco sparverius*
Birds, continued	
Wild turkey	*Meleagris gallopavo*
Northern bobwhite	*Colinus virginianus*
American woodcock	*Scolopax minor*
Mourning dove	*Zenaida macroura*
American crow	*Corvus brachyrhynchos*
House wren	*Troglodytes aedon*
American robin	*Turdus migratorius*
Gray catbird	*Dumetella carolinensis*
Brown thrasher	*Toxostoma rufum*
Loggerhead shrike	*Lanius ludovicianus*
White-eyed vireo	*Vireo griseus*
Yellow-rumped warbler	*Dendroica coronata*
Common yellowthroat	*Geothlypis trichas*
Yellow-breasted chat	*Icteria virens*
Northern Parula	*Parula americana*
Prothonotary warbler	*Protonotaria citrea*
Northern cardinal	*Cardinalis cardinalis*
Bachman's sparrow	*Aimophila aestivalis*
Dark-eyed junco	*Junco hyemalis*
Song sparrow	*Melospiza melodia*
Rufous-sided towhee	*Pipilo erythrophthalmus*
White-throated sparrow	*Zonotrichia albicollis*
Red-winged blackbird	*Agelaius phoeniceus*
Common grackle	*Quiscalus quiscula*
Mammals	
White-tailed deer	*Odocoileus virginianus*
Virginia opossum	*Didelphis virginiana*
Nine-banded armadillo	*Dasypus novemcinctus*
Carolina shrew	*Blarina carolinensis*
Least shrew	*Cryptotis parva*
Prairie mole	*Scalopus aquaticus machrinus*
Gray fox	*Urocyon cinereoargenteus*
Red fox	*Vulpes vulpes*
Black bear	*Ursus americanus*
Raccoon	*Procyon lotor*
Mink	*Mustela vison*
Striped skunk	*Mephitis mephitis*
River otter	*Lontra canadensis*
Bobcat	*Lynx rufus*
Muskrat	*Ondatra zibethicus*
Beaver	*Castor canadensis*
Eastern woodrat	*Neotoma floridana*
Marsh rice rat	*Oryzomys palustris*
Southern golden mouse	*Peromyscus aureolus*
Cotton mouse	*Peromyscus gossypinus*
White-footed mouse	*Peromyscus leucopus*
Fulvous harvest mouse	*Reithrodontomys fulvescens*
Eastern harvest mouse	*Reithrodontomys humulis*
Hispid cotton rat	*Sigmodon hispidus*
Nutria	*Myocaster coypus*
Swamp rabbit	*Sylvilagus aquaticus*
Cottontail rabbit	*Sylvilagus floridanus*
Marsh rabbit	*Sylvilagus palustris*

alternative for monitoring wildlife is to take an indirect approach. Indices such as those provided by habitat suitability index models (Schamberger and Farmer, 1978; U.S. Fish and Wildlife Service, 1981), the Wetland Evaluation Technique (WET; Adamus, 1983), the Hydrogeomorphic Method (Brinson and others, 1994; Smith and others, 1995), or the Rapid Impact Assessment Method (Stein and Ambrose, 1998) can be used to evaluate the suitability of wildlife habitat for key species or species groups.

Selected References

Adamus, P.R., 1983, A method for wetland functional assessment: Washington, D.C., U.S. Department of Transportation, Federal Highway Administration, FHWA-IP-82-23.

Banks, R.C., McDiarmid, R.W., and Gardner, A.L., 1987, Checklist of vertebrates of the United States, the U.S. Territories, and Canada: Washington, D.C., U.S. Department of the Interior, Fish and Wildlife Service, Resource Publication 166, 79 p.

Bookhout, T.A., ed., 1994, Research and management techniques for wildlife and habitats: Bethesda, Md., The Wildlife Society, Inc., 740 p.

Brinson, M.M., Kruczynski, W., Lee, L.C., Nutter, W.L., Smith, R.D., and Whigham, D.F., 1994, Developing an approach for assessing the functions of wetlands, *in* Mitch, W.J., ed., Global wetlands: old world and new: Amsterdam, The Netherlands, Elsevier Sciences B.V., p. 615-624.

Environmental Laboratory, 1987, Corps of Engineers wetlands delineation manual, Technical Report Y-87-1: Vicksburg, Miss., U.S. Army Corps of Engineers Waterways Experiment Station, 165 p. [This, or the current edition of the manual, provides information on field indicators of wetland hydrology, soils, and vegetation.]

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Keeland, B.D., Dowd, J.F., and Hardegree, W.S., 1997, Use of inexpensive pressure transducers for measuring water levels in wells: Wetlands Ecology and Management, v. 5, p. 121-129.

Kentual, M.E., Brooks, R.P., Gwin, S.E., Holland, C.C., Sherman, A.D., and Sifneos, J.C., 1992, An approach to improving decision making in wetland restoration and creation: Washington, D.C., Island Press, 151 p.

Kevin L. Erwin, Consulting Ecologist, Inc., 1990, Agrico swamp west eighth annual report: Mulberry, Fla., Prepared for Agrico Chemical Company.

Ludwig, J.A., and Reynolds, J.F., 1988, Statistical ecology: New York, John Wiley and Sons, 337 p.

Schamberger, M., and Farmer, A., 1978, The habitat evaluation procedures: their application in project planning and impact evaluation: Transactions of the Forty-Third North American Wildlife and Natural Resources Conference, p. 274-283.

Schamberger, M., and Krohn, W.B., 1982, Status of the habitat evaluation procedures: Transactions of the North American Wildlife and Natural Resources Conference, v. 47, p. 154-164.

Schemnitz, S.D., ed., 1980, Wildlife management techniques manual: Washington, D.C., The Wildlife Society.

Smith, R.D., Ammann, A., Bartoldus, C., and Brinson, M., 1995, An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices: Vicksburg, Miss., U.S. Army Corps of Engineers, Waterways Experiment Station, WRP-DE-9, 72 p.

Sprecher, S.W., 1993, Installing monitoring wells/piezometers in wetlands, WRP Technical Note HY-IA-3.1: Vicksburg, Miss., U.S. Army Corps of Engineers, Waterways Experiment Station, USA.

Stein, E.D., and Ambrose, R.F., 1998, A rapid impact assessment method for use in a regulatory context: Wetlands, v. 18, no. 3, p. 379-392.

U.S. Fish and Wildlife Service, 1981, Standards for the development of habitat suitability models, Ecological Services Manual 103: Washington, D.C., U.S. Fish and Wildlife Service, Division of Ecological Services.

Van Horne, B., and Wiens, J.A., 1991, Forest bird habitat suitability models and the development of general habitat models: Washington, D.C., U.S. Department of the Interior, U.S. Fish and Wildlife Service, Research 8, 31 p.

White, T.A., Allen, J.A., Mader, S.F., Mengel, D.L., Perison, D.M., and Tew, D.T., 1990, MiST: a methodology to classify pre-project mitigation sites and develop performance standards for construction and restoration of forested wetlands, Results of an EPA-sponsored workshop: Atlanta, Ga., U.S. Environmental Protection Agency, 85 p.

Chapter 14: Rehabilitation and Management of Existing Forests

Although this guide emphasizes restoration of bottomland forests on sites without tree cover, there are extensive areas of degraded natural forests in need of rehabilitation. Often the degradation is due to past mismanagement such as high grading or holding water late into the growing season in green-tree reservoirs. In other cases, hydroperiod alterations, hurricanes, severe floods, or insect outbreaks may have degraded the stands. Many southern bottomland hardwood stands have deteriorated to such a point that they have little value for timber, wildlife production, recreation, or aesthetics (fig. 14.1).

This chapter presents basic information on bottomland hardwood silviculture. The suite of techniques employed by silviculturists can be used to achieve a wide range of objectives, including forest rehabilitation. The principles described in this chapter can be applied not only to rehabilitating existing degraded stands but also to the long-term management of restoration forests as described in the preceding chapters of this guide.

There are three key steps in planning the management of bottomland hardwood forests: (1) understanding current forest and environmental conditions; (2) clarifying objectives (the desired future condition); and (3) defining feasible actions that will transform the stand to the desired condition. In most cases, the silviculturist has several options for intervening in stand development, as there are multiple silvicultural pathways toward the desired future condition. The choice of silvicultural treatment will affect the financial cost, the nature of intermediate stand conditions, and the time it takes to achieve the desired condition. In general, silvicultural treatments consist of partial to complete removal of the trees on a site. Partial removals may consist of thinnings of desirable species to allow greater growing space of the leave trees or removal of undesirable species. If the silvicultural treatment can be combined with a timber sale, the landowner may be able to accomplish the treatment at no cost or even at a profit. It is imperative that silvicultural decisions are made with clear objectives in mind and with an eye toward rehabilitation success.

Determining Present Site and Stand Conditions

Diagnosing present site and stand conditions requires information to be gathered in an organized and rigorous fashion. The first step in forest management, including rehabilitating degraded bottomland forests, is to determine what currently occupies the site. A simple reconnaissance can give much of the preliminary information

Figure 14.1. Bottomland hardwood stand degraded by years of mismanagement.

needed for planning subsequent forest management. The initial reconnaissance should be followed by a more detailed site inventory before a silvicultural system is selected and interventions are prescribed. These activities should be performed by a knowledgeable forester.

Site Reconnaissance and Inventory

In the reconnaissance, boundaries of the site should be located and possible boundary-related problems identified. Potential problems could stem from trespassing or land-use practices on adjacent tracts, such as burning or herbicide spraying that may endanger the forest to be rehabilitated. Examples of other urgent problems discovered at this stage include destructive grazing, the presence of dump sites containing hazardous materials, or beaver dams in areas where they will cause excessive damage to the stand or limit access to the site. These problems should be addressed immediately.

The operability of the site, including soil and flooding conditions affecting accessibility to logging and other heavy equipment, existence of roads, and other practical considerations that will affect management options, should also be assessed during the reconnaissance. Included in this assessment should be a rough estimate of the timber volume and quality on the site. Getting a contractor to carry out desired management on the site may depend on the existence of enough timber to cover the costs of the operation.

A final goal of the reconnaissance should be to identify logical subunits of the site, called compartments, for subsequent inventory and management. Identifying subunits is important if the project site is large enough to contain different forest types, stands of different ages, or areas with special problems such as lack of access. Readily identifiable compartment boundaries, such as roads, streams, or power lines, should be used when possible.

A more detailed inventory of the site should generally follow the reconnaissance. If an area is large and rehabilitation will proceed over several years, it may be advantageous to delay the inventory until just before the first managed cut (i.e., the first thinning or the regeneration cut). The main advantage of delaying the inventory is that more accurate information on timber volume and quality will be available for setting up a contract with a timber buyer. Several references listed at the end of this chapter describe forest inventory techniques. Most often, the inventory will make use of randomly or systematically located sample plots for the overstory trees and nested subplots for seedlings and saplings. Methods for evaluating regeneration potential are discussed later in this chapter.

Assessment of Site Potential

Site "potential" refers to the combination of relatively unchanging physical factors which affect species composition and stand vigor: soil and landform (characteristics of which determine moisture availability, aeration, and fertility) and hydroperiod (flood frequency, duration, depth, and seasonal timing). These physical factors are not immutable, however, and changes in hydroperiod especially can degrade a site. On the other hand, selectively logging the biggest and best trees of a few species may degrade the stand without lowering the potential of the site.

Often a stand is so degraded that true site potential, in terms of species composition and productivity, is masked. Conversely, one must be careful to avoid attributing a higher potential than is warranted and mistakenly blaming degradation for inherently poor site conditions. A site's potential, and whether it has been degraded, sets limits on what can be achieved by silvicultural intervention. Site potential also determines the general direction of stand development and the likely outcome of any major disturbance that affects the existing stand. Because site potential has to do with physical factors, it is necessary to first place a site within a landscape context; for example, a silviculturist should assess whether a site occurs in the floodplain of a major or minor river system (Hodges, 1998; Kellison and others, 1998). On major river systems, sediment deposition causes a pattern of higher sites (ridges, fronts, natural levees) nearer to present or historic river channels, with lower lying sites farther away (flats). Inactive older channels (sloughs) and depressions are the wettest sites. Each of these "topographic sites" has the potential of being managed as a different compartment. Minor river bottomlands occur within a narrow floodplain, and therefore landform patterning is at a much finer scale. Stands in minor river bottoms may not differentiate into large enough areas to manage as separate compartments.

Each of these differences in topography and hydrology affect the species composition of the individual stands. Eight important species groups of bottomland hardwood forests are described briefly in table 14.1; more detail can be found in Meadows and Stanturf (1997); Hodges (1997); Johnson (1981); and Kellison and others (1988). The adaptation of species important for timber production to specific site conditions can be found in Baker and Broadfoot (1979), and the important silvical characteristics of most bottomland hardwood trees are treated by individual authors in Burns and Honkala (1990). Once a site's potential is understood, it is important to compare that to actual stand conditions and then to diagnose why there may be a difference.

Table 14.1. Species groups and expected regeneratio Meadows and Stanturf, 1997).

	Site Preference			
Species Association	**Major Bottom**	**Minor Bottom**	**Silvicultural System**	**Species Favored**
Cottonwood	Front (new land)		Seed tree with site preparation	Eastern cottonwood
			Clearcut	Sycamore, sweet pecan, green ash, boxelder
Black willow	Bar (new land)		Seed tree with site preparation	Black willow
			Clearcut	Sugarberry, green ash, baldcypress, American elm, overcup oak, bitter pecan, Nuttall oak
Cypress-water tupelo	Swamp	Slough	Group selection	Baldcypress, water tupelo, sometimes green ash, overcup oak, bitter pecan
			Clearcut	Baldcypress, water tupelo, sometimes green ash, overcup oak, bitter pecan, or elm and maple
Elm-sycamore-pecan-sugarberry	Front, high ridge		Group selection or clearcut	Sweetgum, red oaks[1], sycamore, sweet pecan, sugarberry, green ash
Elm-ash-sugarberry	Wide flats		Clearcut or group selection	Elm, green ash, sugarberry, Nuttall oak, willow oak
Sweetgum-red oaks	Ridges	High flats	Group selection	Sweetgum, red oaks, green ash
			Clearcut	Sweetgum, red oaks, and green ash favored, with sweetgum favored the most
			Shelterwood	Red oaks, sweetgum, green ash
Red oaks-white oaks[2]-mixed	Second bottoms, high ridges	Terrace	Shelterwood or group selection	Red oaks, white oaks, hickory, green ash, sweetgum, American hornbeam
Overcup oak-bitter pecan	Low flats, sloughs	Flats	Group selection	Overcup oak, bitter pecan
			Shelterwood	Overcup oak, bitter pecan, Nuttall oak, green ash

[1] Cherrybark oak, laurel oak, Nuttall oak, pin oak, Shumard oak, water oak, and willow oak.

[2] Bur oak, Delta post oak, live oak, overcup oak, swamp chestnut oak, white oak, and swamp white oak.

Site Inventory

Ideally, the inventory should quantify the species composition, timber volume, and quality of the overstory trees. Just as important is the inventory of the seedling and sapling component of the stand. This understory component, called advance regeneration, has the potential to dominate the stand in time. Quantifying advance regeneration helps the silviculturist predict the future species composition of the stand and decide whether planting of desired species will be necessary. Quantifying existing regeneration is particularly important if the management goal is to obtain a large component of oak species (or other heavy-seeded species with limited or unreliable seed dispersal) in the stand.

Advance regeneration can also alert the silviculturist to possible changes in site hydrology; if the flood tolerance of the species making up the overstory and understory differ substantially, hydrologic changes probably have occurred. At this point, the silviculturist will have to decide whether to work with the new hydrologic regime or attempt to restore the former regime.

Oaks are an important component of bottomland hardwood forests, valued for their timber quality, their hard mast production for wildlife, and generally for their aesthetically pleasing growth habit. As a group, oaks, and red oaks in particular, are difficult to perpetuate in successive stands on a site. In addition, oaks are the most likely species to have been selectively removed in high grading. Therefore a key challenge for silviculturists is successfully maintaining a viable oak component, which can be done by ensuring that adequate oak advance regeneration exists before timber removal or by artificial regeneration (i.e., planting seedlings or direct seeding of acorns). Information on oak regeneration potential is critical in most stand rehabilitation efforts. Johnson (1980) developed a system for assessing regeneration potential for a variety of bottomland hardwoods. Belli and others (1999) evaluated Johnson's system for high quality sites in terms of red oaks and green ash, which is another valuable timber species. Their method is based upon 1/100-acre (0.004 ha) circular plots systematically located throughout a stand. Each plot is evaluated for the number of red oak or green ash seedlings in three height classes: less than 1 ft (30 cm), 1 to 3 ft (30-90 cm), and greater than 3 ft (90 cm) tall. In addition, points are given for trees with high potential for producing acceptable stump sprouts (red oak or green ash trees 1 to 5 inch [2.5-12.7 cm] dbh). Each plot can be evaluated for the probability that it will have at least one seedling in a free-to-grow position after three growing seasons. From this information, one can determine the number and distribution of "stocked" plots, an indication of the future stocking of the stand.

Identifying Cause of Site Degradation

The cause of site or stand degradation should be identified. Stand degradation from high grading can often be remedied through vegetation manipulation alone. Alteration of the site by changed hydroperiod, on the other hand, poses broader questions. Can the hydroperiod be restored or the effects of alteration somehow mitigated? Should the rehabilitation effort target a different vegetation assemblage more adapted to the present hydroperiod and site conditions? Hydroperiod alterations caused by flood control projects, dams, or highway construction tend to be irrevocable, at least in the short-term. Flooding caused by beaver dams, however, can be reduced by removing the dam, but ongoing management of beaver population levels will be required to avoid recurring problems. Management of green-tree reservoirs is often politicized, and management of water levels to protect the vigor and survival of the hardwood stand in many instances conflicts with public perception of how to optimize waterfowl habitat. The guiding principle should be to rehabilitate or restore in accordance with existing hydroperiod, unless alteration is feasible, affordable, and within the control of the silviculturist.

Clarifying Objectives

Appropriate silvicultural practices can be designed for any objective. Most common objectives include timber, wildlife habitat for game species, or aesthetics. Increasingly other objectives are considered, including carbon sequestration, biological diversity, nongame mammals and birds, endangered animals and plants, protection of water quality and aquatic resources, and recreation. Different outputs may be sought for each objective. The timber management objective, for example, may be for sawlogs and veneer logs, or for pulpwood. Appropriate timber management, in particular rotation length, will vary according to the desired product size. Appropriate management techniques for wildlife will also vary for different species. Even Neotropical migratory birds have different habitat requirements, from mature closed forests to early successional seres. Choosing the appropriate silvicultural techniques presents a challenge for those individuals managing for apparently incompatible objectives. Slight modifications in technique may have negligible impacts on outcomes or outputs for one objective but major effects on another objective. Clarity of objectives, combined with an adequate understanding of feasible goals developed from information on current conditions, allows the silviculturist to choose a silvicultural system that will maximize satisfaction of multiple objectives; however, no single objective is usually optimized when multiple objectives are undertaken. Nevertheless, the chosen system may be adjusted to minimize impacts on other ecosystem functions.

The most developed basis for specifying a silvicultural system to meet an objective is for timber production. To the extent that we know the habitat requirements for a wildlife species, we can prescribe an appropriate silvicultural system that will provide suitable habitat. All species of bottomland hardwoods provide some benefit to wildlife (table 14.2), but we lack the knowledge to specify optimal habitat conditions for many species. Nevertheless, most objectives can be tied to some combination of vegetation species composition and stand structure, which can be manipulated by silvicultural techniques.

Choosing the Silvicultural System

Silvicultural systems in southern bottomland hardwoods integrate regeneration and intermediate treatments in an orderly process for managing stand development (Meadows and Stanturf, 1997). Techniques can be designed for manipulating species composition and stand structure to meet any management objective. Species favored under any silvicultural system can support several objectives. Although the greatest emphasis is usually placed on maintaining an oak component, forests can be managed without oaks and still yield multiple benefits. Silvicultural systems are commonly divided into even-aged and uneven-aged management, with the regeneration method used defining the system. Even-aged regeneration methods include clearcut, seed-tree, and shelterwood. Uneven-aged methods include single-tree and group selection (Meadows and Stanturf, 1997). In practice, there are many variations of these practices with some overlap and hybridization. A general guide to the types of regeneration expected under different silvicultural systems applied to important bottomland hardwood associations is given in table 14.1.

Management Versus Regeneration

The silviculturist must initially decide whether the degraded stand has the potential to attain the future desired condition through judicious manipulation, or whether the stand is so lacking in vigor, stocking, or acceptable species that the only alternative is to regenerate. Manuel and others (1993) developed a model to help make this decision. Their model is based on expert judgement and is constrained to consider only clearcutting for regeneration. It has been calibrated for a limited set of timber management objectives, but the approach is valid for any management objective. Each tree in a sample from the stand is evaluated for its contribution to future stocking, based on species, size (dbh), crown class, merchantable height, butt log grade, and vigor. This approach can be extended to include other management objectives and additional regeneration techniques.

Is Oak An Objective?

If maintaining oak in the stand is necessary to meet objectives, extra attention to regeneration potential is needed and extraordinary steps may be necessary. Clatterbuck and Meadows (1993) summarized the complexity of attempting to regenerate oaks in bottomland hardwood forests. Although no blanket prescription can account for all the factors which impact oak regeneration potential, their generalized prescription offers the best approach present knowledge can provide (table 14.3).

A regeneration evaluation is necessary at the outset. A modified system such as that of Belli and others (1999), where points are assigned based on species and size of advance regeneration can be used. For example, if a regeneration plot has at least 20 points from oak advance reproduction or stump sprouting potential, the probability of obtaining at least one free-to-grow oak stem at age three is 83% or more. If most of the regeneration plots in a stand meet this criterion, the regenerated stand has a high probability of oak dominance at maturity. We recommend that 80% of the plots in the entire stand meet this level of oak stocking. This is a judgement, however, and should be adjusted depending upon site conditions and landowner objectives. For example, if most of the points come from large seedlings (greater than 1 m or 3 ft tall), a lower probability level may be justified. On the other hand, sites prone to growing season flooding may require a more stringent criterion.

When the prospects for oak regeneration are good, the stand should be harvested while trees are dormant to maximize stump sprouting. All residual stems 2 inches dbh and larger should be felled to create the proper light environment for the oak regeneration and to minimize competition from other species. Retaining some stems in a clearcut (depending on the purpose of these residual trees, this may be called a deferment cut, clearcut with residuals, or an irregular shelterwood) may be necessary to meet wildlife or aesthetic objectives.

A follow-up examination to determine regeneration stocking at age three is needed to guide future management. Experience has shown that as few as 150 free-to-grow oaks per acre (370 per ha) at age three will result in an oak dominated stand.

Table 14.2. S
LA = leaf gall aphids; BU = buds; IB = inner bark; BA = bark.

Species	Deer	Turkey	Squirrel	Waterfowl	Quail	Songbirds	Raccoon	Beaver	Other
Ash, green	FO				S	S			S[1]
Ash, pumpkin						S			S[1]
Ash, white	FO				S	S			S[1]
Birch, river	FO					S			S[1]
Buckthorn bumelia						FR			
Buttonbush	FO			S				FO	
Cottonwood, eastern	FO	LA							
Cypress, bald (baldcypress)									S[1]
Dogwood, swamp	FO	FR	FR			FR	FR		FR[2], FO[3]
Elm, American						FR			
Elm, cedar						FR			
Elm, water				FR					
Elm, winged						FR			
Blackgum	FO,FR	FR				FR	FR		FR[1,2]
Sweetgum			S, BU	S	S			IB	S[1]
Hawthorn		FR	FR	FR	FR	FR			FR[1]
Pecan, sweet	FR		FR				FR		
Hickory, water			FR	FR					FR[1]
Holly, American	FO	FR			FR	FR			
Holly, deciduous	FO	FR			FR	FR			FR[1]
Hornbeam, American	FR	FR							
Locust, black[6]	FR		FR		FR				FO[3], FR[1,3]
Locust, honey[6]	FO		S		S				
Locust, water	FR		FR						FR[3]
Boxelder	FO					S			S[1]
Maple, red	FO		S, BU			S			S[1]
Mulberry, red	FO	FR	FR			FR	FR		FR[1] , BA[3]
Oak, cherrybark	FO,FR	FR	FR	FR		FR			FR[1]
Oak, Delta post	FR	FR	FR			FR			FR[1]
Oak, Nuttall	FO,FR	FR	FR	FR					FR[1]
Oak, overcup	FR		FR						FR[1]
Oak, Shumard	FO,FR	FR	FR			FR			FR[1]
Oak, swamp chestnut	FR,FO		FR						FR[1]
Oak, swamp white	FR	FR	FR	FR			FR		FR[1]
Oak, water	FO,FR	FR	FR	FR	FR				FR[1]
Oak, white	FR,FO		FR			FR	FR		FR[1]
Oak, willow	FO,FR	FR	FR	FR		FR			FR[1]
Pawpaw							FR		FR[2]
Persimmon, common	FO,FR	FR			FR	FR	FR		FR[1,2,4]
Privet, swamp				FR		FR			FR[1]
Sassafras	FO	FR	FR		FR	FR	FR		FR[5]
Sugarberry	FO				FR	FR			FR[1]
Sycamore, American						S			
Tupelo, water[6]	FO,FR		FR	FR		FR	FR		
Willow, black									
								IB	

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[1] Small mammals
[2] Opossum
[3] Rabbit
[4] Skunk and fox
[5] Black bear
[6] Flowers furnish nectar for honey bees

Table 14.3. Decision key for choosing a regeneration procedure for bottomland oaks (Clatterbuck and Meadows, 1993; Belli and others, 1999)

		Go to
1.	Regeneration Evaluation	
	a. 20 points or more, average of all plots; oak prospects good	2
	b. Less than 20 points, oak prospects poor	6
2.	Treat and harvest during dormant season; control residual stems prior to next growing season	3
3.	Evaluate at age 3	
	a. More than 150 free-to-grow oaks per acre	4
	b. Less than 150 free-to-grow oaks per acre	5
4.	Leave alone or clean, weed, or thin if needed	
5.	Oak stocking is less than adequate	
	a. Accept	
	b. Convert to plantation	
6.	Promote oak advance reproduction and evaluate again	
	a. Increase light to forest floor (understory removal and/or overstory reduction, shelterwood)	1
	b. Shelterwood with understory removal and supplemental planting of oak seedlings	1
	c. Convert to plantation	

If oak regeneration is inadequate in the current stand (table 14.3), the challenge is to create the proper light conditions on the forest floor to promote seedling growth. Reducing the overstory and removing the understory through a shelterwood treatment can be successful if small oak seedlings are already present. It may even be possible to time the shelterwood treatment (see shelterwood section, this chapter) with a good mast year; otherwise underplanting oak seedlings before the final overstory removal can augment the shelterwood. This may require releasing the oak seedlings from competition by using herbicides. There are no guidelines on how to accomplish this successfully. Another approach is to supplement a clearcut by planting or direct seeding of oak but again, no guidelines are available.

Managing the Existing Stand

In a stand with trees of commercial value, a logical sequence of management actions would be (1) initial intermediate management, consisting of an "improvement cut" to favor a desirable species composition and to increase the quality and value of the stand; (2) advanced intermediate management, where thinning is used mostly to favor growth on residual trees but also to improve stand value; and (3) regeneration cutting. Intermediate stand management in most bottomland hardwood situations is a combination of improvement cutting and thinning. The relative emphasis changes with the degree of stand management (initial versus advanced).

In the short term, the silviculturist will be most concerned with improvement cutting because thinning and regeneration cuts may not be needed for 10 or more years. In the case of extremely degraded stands with inadequate advance regeneration, however, it may be necessary to bypass the first two management steps and go straight to a regeneration cut. A general guideline used by some foresters to decide whether to proceed straight to a regeneration cut is shown in figure 14.2. If the average basal area per acre for a stand of a given age is below the line, then the stand is promptly cut. For most stands older than 40 years, basal areas below 60 ft^2 per acre indicate the need to regenerate. More precise guidance is available in stand density diagrams that take into account average stem size and age.

Timber Stand Improvement

By definition, degraded stands have a history of high grading, liquidation cuts, fire, and other destructive influences that have resulted in a high proportion of trees that are undesirable as future growing stock. Low-grade, overcrowded, damaged, diseased, and cull trees, as well as exotic or otherwise undesirable species, may be occupying space and competing for light, water, and nutrients that ideally could be supporting more valuable trees. Therefore the first stand manipulation is usually a judicious improvement cut designed to "clean up" the forest.

In ideal cases, the stand will be accessible and there will be enough timber to interest potential buyers. In such a situation, timber stand improvement can be done at no cost (or possibly even at a profit) to the landowner. Some desirable growing stock may need to be cut to make openings for regeneration or to have enough timber to interest a buyer. The goal, however, should be to cut the over-mature, damaged, or dying trees of marketable size and quality. One should not remove a large component of desirable growing stock just to make

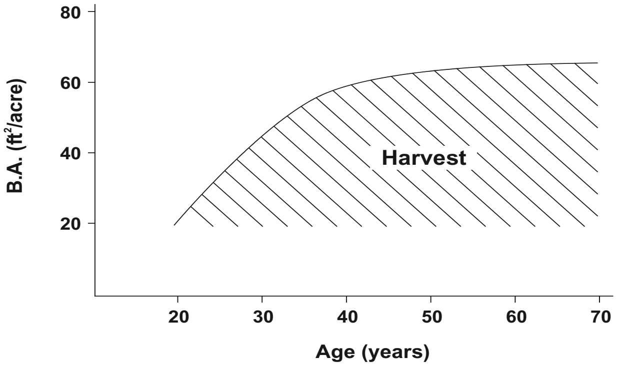

Figure 14.2. A generalized guide for regenerating southern hardwoods based on basal area (measured in ft^2 per acre) of desirable trees and stand age (redrawn from Kellison and others, 1988).

a sale, as such trees are often growing at a high rate and will be much more valuable to the landowner in the future.

Landowners unfamiliar with contracting with buyers for removal of timber are well advised to consult with a professional forester. A properly designed and supervised timber sale should lead to the improvement of the forest. Under the wrong conditions, however, a buyer may end up removing trees that should remain, damaging remaining trees in felling or skidding of harvested trees, creating inordinate amounts of soil disturbance, or degrading water quality of adjacent streams (fig. 14.3).

After marketable trees are cut and removed, cull and otherwise undesirable trees that remain should be killed to enlarge or clear openings for regeneration. Injection is the usual method of killing unwanted trees. Generally, injection just after full leaf-out in the spring gives good results, but satisfactory results have also been obtained with applications in other seasons. Girdling is another method that is occasionally used to kill unwanted trees, but this is often unsuccessful when used alone because trees can heal over incomplete wounds and girdled trees may sprout.

It should be kept in mind, of course, that a "clean" forest from a strictly timber management perspective may not be the goal of the silviculturist. Mature cane breaks (fig. 14.4) will not bring any financial return to the landowner but they provide habitat for numerous wildlife species (including swamp rabbits and several species of rare warblers). Leaving some large, poorly formed trees and snags may be beneficial to several species of wildlife or may meet other objectives (fig. 14.5). As with other silvicultural techniques, timber stand improvement should be viewed as a flexible tool that can accomplish a variety of objectives.

Thinning

Once timber stand improvement has produced a stand consisting of good quality trees at desirable spacing, growth rates of the remaining "leave" trees should increase. Eventually, the leave trees will fully occupy the space opened up by the removal of undesired trees and begin to compete intensely with each other. Thinning at this point allows for the use of trees that would otherwise die and allows for distribution of growth over fewer, larger trees. Thinning has the additional advantages of increasing mast production in the overstory and allowing more light to reach the forest floor. This stimulates understory and midstory plant growth, which increases vertical structure important to some Neotropical migratory birds.

Thinning has not been widely practiced in southern bottomland hardwood stands, especially in stands with

Figure 14.3. Example of damage caused by poor logging practices.

Figure 14.4. Mature cane brakes provide habitat for numerous wildlife species.

only pulpwood or smaller sized trees (i.e., less than about 25-30 cm [10-12 inches] dbh). As markets develop for pulpwood and firewood, thinning is becoming more common. The first commercial thinning typically occurs when trees reach small sawtimber size, about 35 cm (14 inches) dbh. A second thinning may be conducted when trees reach 50-56 cm (20-22 inches) dbh. Earlier thinning (precommercial) is practical from an economic standpoint if one of the major goals of management is production of sawtimber.

Because of inherent growth differences among species, it would be hard to give an average age for the first thinning. Cottonwood may reach merchantable size by age 5 to 10 years, whereas it may take green ash 20 to 30 years to reach pulpwood or small sawtimber size. Findings thus far in natural and planted stands offer some guidelines for thinning (Meadows, 1996). Thinning should begin early, and larger trees with well-developed crowns should be favored. For good diameter growth, most species require a minimum live crown to total height ratio of 40%. Trees with less crown are usually in a subordinate position, so thinning is from below (i.e., the trees removed in the thinning are usually partially or completely overtopped by other trees).

Frequent light thinnings are better than infrequent heavy thinnings. Light thinnings allow fuller use of the site and less chance for epicormic branches to develop on the leave trees. One disadvantage of frequent thinnings, though, is the greater chance of logging damage to the leave trees. As a stand matures, thinning should be used to develop advance reproduction of desirable species so that the need for corrective measures at the time of regeneration will be less.

Regeneration

Bottomland hardwoods reproduce naturally and prolifically through seedlings established in the understory, through sprouts that emerge from stumps or roots of cut trees, or through seedlings that start in new openings. As long as there are no fundamental changes to the site, management of the natural regeneration can generally be relied upon to yield the desired forest composition.

As a rule, silviculturists should rely on natural regeneration. Artificial regeneration, however, will be needed for rehabilitation when none of the natural means of reproduction can be counted on to provide adequate numbers of desirable species. This situation arises where there is inadequate advance regeneration of desirable

Figure 14.5. Snags left in a clearcut on Scott Paper land near Mobile, Alabama.

species and there are no mature trees of desired species in the overstory or adjacent to the site to provide a seed source. In such cases, the silviculturist has two main alternatives. First he or she must try to increase the component of desirable species by planting before (enrichment underplanting) or after a regeneration cut (supplemental planting). Second, the silviculturist can take the more drastic measure of converting the stand to another vegetation type by clearcutting the site, shearing all remaining trees and saplings, and preparing the soil to plant seedlings of one or more species (fig. 14.6). Generally, this will only be warranted if the site has been captured by invasive exotic species such as Chinese tallow, Japanese privet, or melaleuca.

Regeneration Cuts

A landowner may wish to manage a stand as an old-growth forest without any human intervention. Over time, natural mortality and gap phase regeneration will convert the forest to shade tolerant species. Otherwise, all stands will eventually reach a stage when it is appropriate to harvest some or all of the large trees. This not only allows for an economic return from the stand, but also gives the landowner the ability to control the future composition of the stand to meet any of a variety of management goals. By proper choice and application of a regeneration system, the landowner can help ensure that the desired type of forest will occur on the site for many years to come.

Bottomland hardwoods can be managed as even-aged or uneven-aged forests. Silvicultural systems used for even-aged management are clearcuts, shelterwood cuts, and seed tree cuts. The primary silvicultural system for uneven-aged management is single-tree selection. Group selection is technically an uneven-aged management system, but as practiced in bottomland hardwood forests, it should be viewed as a compromise between even- and uneven-aged management. All of these systems can be used effectively in bottomland hardwood forests. The choice of silvicultural system will depend primarily on the management goals for the forest, as constrained by the initial condition of the stand. Even-aged management, in particular clearcutting, is the most common form of management when timber is the primary goal or when rehabilitating a high-graded stand. Shelterwood and group selection are more commonly used when wildlife management is an important goal, when

Figure 14.6. Natural forest site that has been clearcut, sheared, root-raked, and disked.

aesthetics are important, and when adequate advance regeneration is not present. Group selection can be used for timber production in fully stocked stands, and variations on shelterwood can be used especially when attempting to regenerate oak.

Clearcuts

Clearcutting involves the cutting and removal of all merchantable trees in an area of about 4 ha (10 acres) or more. Typically, the residual trees, which are comprised of undesirable species or are of poor quality and may interfere with regeneration of desirable trees, are either cut down and left in place or killed by injection or girdling. The site usually will be left to regenerate naturally, although site preparation, supplemental planting, and other measures may be applied to control species composition. A clearcut site will go through a jungle-like stage for about 10 years before individual stems begin to restore a forest-like appearance to the area (fig. 14.7).

Clearcutting is designed to favor the reproduction of shade-intolerant species, which also tend to be the more economically valuable species. While often criticized as a destructive and unsightly form of forest management, clearcutting with natural regeneration repeatedly has been demonstrated to be effective for regenerating nearly every major forest type found on bottomland hardwood sites in the Southeast. The aesthetic impacts and risk of erosion associated with clearcutting are real but are less in relatively flat bottomland settings as compared to steep mountainsides.

As a general rule, clearcutting with natural regeneration will tend to favor shade-intolerant, light-seeded species that are easily transported by wind or water (see table 4.1). Species that regenerate from coppice such as the oaks must be present prior to cutting as large seedlings or small trees. Conversely, seedlings of more shade-tolerant species such as hickories, elms, ashes, ironwood, and some oaks tend to become established in small openings.

To the silviculturist, it will be appropriate to employ clearcutting as the first step in rehabilitating a stand that is so completely degraded that there is very little advance regeneration of desirable species. In such cases, there is little point in attempting to manipulate the stand by timber stand improvement and thinning. Essentially starting over by clearcutting with natural regeneration and possibly some planting, or totally by artificial regeneration, will be the most efficient means of rehabilitation.

Shelterwood Cutting

The goal of shelterwood cutting is the same as clearcutting—to favor species that require high light levels to regenerate. With a shelterwood cut, however, the overstory is harvested in at least two stages. In the first stage, a large portion of the existing overstory (perhaps about 50%) is harvested. Trees that are left are generally

Figure 14.7. Five to ten-year-old regenerating clearcut.

of good quality and expected to be good seed producers (fig. 14.8). After about 5-8 years, either all or about half of the remaining overstory trees are removed. In the latter case, the remaining trees are generally harvested in a third cut after another 5-8 years. Shelterwood may be combined with the underplanting of oaks before final overstory removal. Usually midstory removal is necessary in bottomland hardwoods to gain the full benefits of the shelterwood system.

The main purpose of the shelterwood system is to favor regeneration of species with limited seed dispersal and those that regenerate best in partial shade. Oaks, for example, are believed to respond well to shelterwood regeneration when there are sufficient individuals in the existing overstory. The shelterwood system is also a good alternative to clearcutting when aesthetics are important and complete overstory removal in one cut is not an option.

Seed Tree System

The purpose of the seed tree system is to provide a seed source after a complete overstory removal. Theoretically, heavy-seeded species such as oaks can be regenerated by this method, but in reality this method regenerates light-seeded species in bottomland hardwoods. Approximately 25 per ha (10 per acre) are usually retained after the first cut, so the area will resemble a clearcut with just a few, large scattered trees remaining. In appearance, this is the same as a deferment cut for aesthetics or leaving potential den trees for wildlife. What separates these variants on even-aged management is the purpose for leaving residual trees.

As a regeneration method, seed tree cuts are more effective for light seeded species such as sweetgum. When coupled with intensive site scarification, it is the recommended method to naturally regenerate Eastern cottonwood and black willow. Experience suggests that bottomland hardwood stands dominated by oaks respond to a seed tree cut as if they were clearcut (i.e., by advance regeneration, by sprouts, and by germination of existing seeds or seeds brought in by wind, water, or animals). Furthermore, the remaining trees often become degraded by epicormic branching, lightning strikes, and wind damage, and therefore lose much of their economic value.

Single-Tree Selection

This system involves the selective removal of individual mature trees at regular intervals. It may also be accompanied by deadening (i.e., injection, girdling) or

Figure 14.8. Shelterwood cut.

removal of unmerchantable trees. Because single-tree selection opens relatively small holes in the canopy, it tends to favor regeneration of species that are shade tolerant. Repeated application of single-tree selection in a stand will shift species composition to the less valuable, more shade-tolerant sugarberry, boxelder, elms, maples, and hickories (table 14.1).

Properly practiced, this method can be very effective for maintaining a relatively dense uneven-aged forest over a large area. It can, however, result in the degradation of the forest. In fact, many of the degraded bottomland hardwood forests that are the subject of this chapter were created by what might be considered a very poor form of single-tree selection. Too often, only the best trees were selected for harvest. If this cycle is repeated, then over time the stand will become dominated by a mix of damaged, diseased, and poorly formed trees and trees of undesirable species. This form of management is known as high-grading.

Single-tree selection is not generally viewed as economically feasible because it leaves species which are generally less valuable and also because it requires frequent small harvests, thereby sacrificing the economy of scale of larger harvests. Frequent entry into the stand with heavy logging equipment also poses the risk of damage to the remaining trees and the introduction of diseases. Such stresses may predispose a stand to insect outbreaks.

Group Selection

The goal of group selection is to develop a patchy environment made up of numerous very small even-aged groups. This is accomplished by making numerous scattered large openings (small patch clearcuts) ranging in size from 1 to several acres (fig. 14.9). The distinction in opening size between group selection and patch clearcut is a blurry one. A 10-acre cut can be viewed as a very large group selection or a small clearcut, depending on one's perspective. The real difference is whether the resultant stand will be managed as an uneven-aged stand or several even-aged stands.

The group selection system has several advantages. By creating sufficiently large openings, it favors the more economically valuable shade-intolerant species such as oaks. In addition, by creating a patchy environment of several different age classes, it favors numerous species of wildlife. As the openings are small and scattered, group selection is more aesthetically pleasing

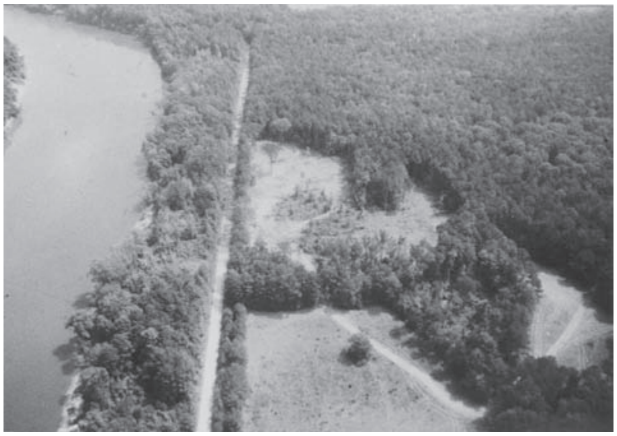

Figure 14.9. Aerial photo of several group selection cuts.

than larger clearcuts. Although group selection may not be desirable for maximizing income from timber production, it has become widely used on wildlife refuges and other areas where wildlife management is a primary goal. Disadvantages include the necessity of more entries into a stand and higher risk of logging damage to residual trees, higher incidence of disease from the logging damage, and the need for more demanding management in terms of expertise, inventory, and record keeping.

Bringing Back the Bush

The preceding sections have covered traditional silvicultural approaches to rehabilitating degraded forests. These are the most appropriate techniques for rehabilitating relatively large tracts and those tracts where timber harvests are feasible. In some situations, especially on very small tracts and in urban settings where exotic vegetation is a primary concern, a smaller scale but more labor-intensive approach might be more acceptable.

An interesting approach to this type of rehabilitation has developed in Australia under the catchphrase "bringing back the bush" (Bradley, 1988). This approach was developed to restore small areas of Australian bush in urban settings that have been overrun by exotic plants.

The Bradley method is based on the gradual weeding out of the exotics by working through the tract in small increments. Landowners and managers are advised to follow three principles that guide this approach: (1) work from areas of native plants towards weed-infested areas, (2) make minimal disturbance, and (3) let native plant regeneration dictate the rate of weed removal. From the third principle, it should be clear that this is a slow approach to rehabilitation. It also requires a fairly high degree of knowledge about the growth habits and ecology of plant species and is very labor intensive.

The best way to apply this approach may be to work with knowledgeable volunteers to rehabilitate a small tract of forest in or near an urban area. The most valuable aspect of this approach may be as a tool for promoting environmental awareness and education.

Selected References

Baker, J.B., and Broadfoot, W.M., 1979, Site evaluation for commercially important southern hardwoods: New Orleans, La., U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, General Technical Report SO-26.

Beattie, C.T., and Levine, L., 1983, Working with your woodland: A landowner's guide: Hanover and London, University Press of New England, 310 p.

Belli, K.L., Hart, C.P., Hodges, J.D., and Stanturf, J.A., 1999, Assessment of the regeneration potential of red oaks and ash on minor-bottoms of Mississippi: Southern Journal of Applied Forestry, v. 23, no. 3, p. 133-138.

Burns, R.M., and Honkala, B.H., 1990, Silvics of North America, v. 2, hardwoods: Washington, D.C., U.S. Department of Agriculture, Forest Service, Agricultural Handbook 654, 877 p.

Bradley, L., 1988, Bringing back the bush: the Bradley method of bush regeneration: Chicago, Landsowne Press, 111 p.

Clatterbuck, W.K., and Meadows, J.S., 1993, Regenerating oaks in the bottomlands, *in* Loftis, D.L., and McGee, C.E., eds., Oak regeneration: serious problems, practical recommendations: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-84, p. 184-195.

Hodges, J.D., 1997, Development and ecology of bottomland hardwood sites: Forest Ecology and Management, v. 90, p. 117-126.

Hodges, J.D., 1998, Minor alluvial floodplains, *in* Messina, M.G., and Conner, W.H., Southern forest wetlands, ecology and management: Boca Raton, Fla., Lewis Publishers, p. 325-341.

Johnson, R.L., 1980, New ideas about regeneration of hardwoods, *in* Proceedings of Hardwood Committee's Symposium on Oak Regeneration: Atlanta, Ga., Southeastern Lumber Manufacturing Association, p. 17-19.

Johnson, R.L., 1981, Wetland silvicultural systems, *in* Jackson, B.D., and Chambers, J.L., eds., Timber

Harvesting In Wetlands: 30th Annual Forestry Symposium: Baton Rouge, La., Louisiana State University, Division of Continuing Education, p. 63-79.

Kellison, R.C., Martin, I.P., Hansen, G.D., and Lea, R., 1988, Regenerating and managing natural stands of bottomland hardwoods: Washington, D.C, American Pulpwood Association, APA 88-A-6, 26 p.

Kellison, R.C., Young, M.J., Braham, R.R., and Jones, E.J., 1998, Major alluvial floodplains, *in* Messina, M.G., and Conner, W.H., Southern forest wetlands, ecology and management: Boca Raton, Fla., Lewis Publishers, p. 291-323.

Kennedy, H.E., Jr., and Johnson, R.L., 1984, Silvicultural alternatives in bottomland hardwoods and their impact on stand quality, *in* Guldin, R.W., ed., Proceedings of the 14th Annual Southern Forest Economics Workshop, March 13-15, 1984, Memphis, Tenn., p. 6-18.

Manuel, T.M., Belli, K.L., Hodges, J.D., and Johnson, R.L., 1993, A decision-making model to manage or regenerate southern bottomland hardwood stands: Southern Journal of Applied Forestry, v. 17, no. 2, p. 75-79.

McGee, C.E., 1986, The first decision: to rehabilitate or to regenerate immature low-quality hardwoods, *in* Smith, H.C., and Eye, M.C., eds., Proceedings: Guidelines for Managing Immature Appalachian Hardwood Stands: Morgantown, W.Va., West Virginia Books, p. 134-139.

McKevlin, M.R., 1992, Guide to regeneration of bottomland hardwoods: Asheville, N.C., U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-76, 35p.

Meadows, J.S., 1996, Thinning guidelines for southern bottomland hardwood forests, *in* Flynn, K.M., ed., Proceedings of the Southern Forested Wetlands Ecology and Management Conference, March 25-27, 1996, Clemson, S.C.: Clemson, S.C., Consortium for Research on Southern Forested Wetlands, Clemson University, p. 98-101.

Meadows, J.S., and Stanturf, J.A., 1997, Silvicultural systems for southern bottomland hardwood forests: Forest Ecology and Management, v. 90, p. 127-140.

Putnam, J.A., Furnival, G.M., and McKnight, J.S., 1960, Management and inventory of southern hardwoods: U.S. Department of Agriculture Handbook No. 181, 102 p.

Smith, D.M., 1986, The practice of silviculture (8th ed.): New York, John Wiley and Sons, 527 p.

Stanturf, J.A., and Schoenholtz, S.H., 1998, Soils and landforms, *in* Messina, M.G., and Conner, W.H., Southern forest wetlands, ecology and management: Boca Raton, Fla., Lewis Publishers, p. 123-147.

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Glossary

Advance regeneration - Advance growth seedlings or saplings that develop and are present in the understory.

Adventive plants - Nonnative plants that have been introduced to an area but have not become permanently established.

Basal area - The cross-sectional area of a stand of trees measured at breast height (140 cm or about 4 ft 6 inches aboveground). The area is expressed in square meters per hectare (ft per acre) and is a measure of stocking density.

Broad-leaved - Characterizing plants that have leaves that are broad and flat rather than needle-shaped.

Clustering - With respect to the planting of seed or seedlings, clustering refers to planting in groups within close proximity of each other so that cross-fertilization within species can occur with some level of certainty.

DBH (diameter at breast height) - The diameter of a standing tree measured 140 cm (4.5 ft) from the ground.

Deciduous - Pertaining to perennial plants that lose their leaves part of the year, that is, hardwood trees such as oak, hickory, and maple.

Epicormic branching - The development of small branches along the bole, or trunk, of a tree. This often develops in response to thinning operations where substantially greater sunlight penetrates to the tree stems.

Even-aged management - Silvicultural system in which the individual trees originate at about the same time and are removed in one or more harvest cuts, after which a new stand is established.

Exotic species - Species that are not native to an area and have become naturalized.

Gap phase regeneration - Progressive changes in community structure, composition, and diversity resulting from the canopy gap created by the death of individual trees (as a result of events such as old age, wind, lightning strikes, insect attacks, etc.) being filled by young individuals of the same or other species.

Green manure - Refers to herbaceous plants that are plowed under while still green to add large quantities of organic matter to the soil, improving soil structure.

Green-tree reservoir - Any impoundment created with the intention of flooding a forested area for a portion of the year, yet retaining the forest cover. Green-tree reservoirs are usually flooded during a portion of the fall and winter to provide waterfowl habitat. Quite often, however, the tree species desirable for waterfowl habitat are gradually killed by the repeated flooding.

Hard mast-producing - Species such as oaks, pecans, or hickories that produce a large nut (acorn) that in turn provide food for a variety of wildlife such as deer, turkey, hogs, and some waterfowl (see heavy-seeded species).

Heavy-seeded species - Species such as oaks, pecans, or hickories that have heavier seeds. These species are generally believed to provide the greatest overall value to wildlife such as deer, turkey, squirrel, and waterfowl.

Herbaceous - Soft and green vegetation which dies back to the ground each year, generally containing little woody tissue.

High grading - Forest harvesting where only the most commercially valuable trees are cut. This method of harvest usually results in a forest dominated by undesirable or weedy tree species.

Hydric - Characterized by or requiring an abundance of moisture.

Hydrologic regime - The pattern of water level dynamics, generally referring to the timing, frequency, depth, and duration of aboveground flooding, but hydrologic regime also refers to belowground water level fluctuations.

Hydroperiod - Generally synonymous with hydrologic regime, but hydroperiod is often considered to refer to aboveground flooding only.

Improvement cutting - A cutting made in a stand past the sapling stage primarily to improve composition and quality by removing less desirable trees of any species.

Initial management - The first management action being performed as part of a long-term multiphase management plan for a given forest stand.

Invader - Any species that disseminates to and becomes established on a site without human intervention can be considered an invader. Invading seedlings can be either desirable or undesirable. The term invader does not refer only to exotic species.

Light-seeded species - Species such as ash, elm, sweetgum, and sycamore that have light weight seeds that can be easily dispersed by wind or water. Many of these seeds, however, can also be dispersed by animals.

Mesic - Characterized by intermediate moisture conditions that are neither excessively wet nor dry.

Nonpoint source pollution - Pollution that is not from a single, well-defined site such as a factory. Runoff from agricultural fields is generally considered nonpoint source.

Palustrine system - A classification by Cowardin and others, 1979, that includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ppt.

Provenance - The original region in which an individual of any plant or animal species was found. Provenance tests take individuals of any selected species from several regions and grow them in a common area (plantation) to search for maximum growth or productivity for that species.

Regeneration - The natural or artificial replacement of old trees with new tree growth.

Self-incompatible species- Plant species for which one flower on an individual cannot fertilize another flower on the same individual.

Sere - Collectively, all temporary plant communities in a chronosequence of change, as different species invade and later dominate or are competitively excluded from a given local area.

Shelterwood cut - A cut in which the mature stand is generally removed in a series of two or more cuts, the last of which is when the new even-aged stand is well developed.

Silviculture - The science and art of regenerating and managing a forest to meet specific objectives.

Soil horizon - A distinct layer of soil parallel to the surface that has definitive physical, chemical, and hydrologic characteristics.

Stand - A contiguous group of trees sufficiently uniform in age class distribution, composition, and structure, and growing on a site of sufficiently uniform quality to be a distinguishable unit.

Stocking - An indication of growing-space occupancy relative to a preestablished standard.

Thinning - Intermediate cuttings aimed primarily at controlling growth of timber stands by adjusting stand density.

Tiling - The placement of drain tiles below the ground to eliminate excess flooding or soil saturation.

Understory - Any plants growing under the canopy formed by other plants, particularly herbaceous and shrub vegetation under a brushwood or tree canopy.

Uneven-aged management - Silvicultural system in which individual trees originate at different times and result in a forest with trees of various ages and sizes. Harvest cuts are often on an individual-tree selection basis.

Selected References

Burns, R.M., and Honkala, B.H., 1990, Silvics of North America, v. 2, hardwoods: Washington, D.C., U.S. Department of Agriculture, Forest Service, Agriculture Handbook 654.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats: U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-79/31. 103 pp.

Stokes, B.J., Ashmore, C., Rawlins, C.L., and Sirois, D.L., 1989, Glossary of terms used in timber harvesting and forest engineering: New Orleans, La., U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, General Technical Report SO-73, 33 pp.

U.S. Department of Agriculture, Forest Service, 1995, Final environmental impact statement for the management of red-cockaded woodpecker and its habitat on national forests in the southern region: Washington D.C., U.S. Department of Agriculture, Forest Service, Southern Region.

U.S. Department of Agriculture, Forest Service, 1996, Final environmental impact statement (FEIS) for the revised land and resource management plan for national forests and grasslands in Texas: U.S. Department of Agriculture, Forest Service, Southern Region.

U.S. Department of Agriculture, Forest Service, 1997, Draft environmental impact statement: draft revised land and resource management plan for Kisatchie National Forest: U.S. Department of Agriculture, Forest Service, Southern Region.

Appendix A
Society of American Foresters Cover Type Descriptions

The cover type descriptions listed in this manual for bottomland hardwoods are from Society of American Foresters (SAF) publication, "Forest Cover Types of the United States and Canada," reprinted verbatim with permission from Eyre, 1980. Numbers listed below the cover types refer to the classification system used by the SAF. For a more complete list of forest cover types or for scientific names of the common names used in the cover type descriptions, please see Eyre, 1980.

River Birch–Sycamore
61

Definition and composition. River birch and sycamore, commonly found along rivers and streams in eastern North America, may be recognized as a type when occurring together as dominants in floodplain or bottomland forests. River birch usually has the greater density of stems, but sycamore may be more conspicuous because of its generally greater size and many stem sprouts (Fowells 1965). The type is of minor importance in its contribution to forest cover except in relatively narrow bands of about 30 m (100 ft.) on frequently flooded, moist alluvial soils.

Associated tree species may include black willow at the edge of the river, and farther back, other flood-tolerant species such as sweetgum, cottonwood, red maple, silver maple, boxelder, hackberry, American elm, slippery elm, walnut, and butternut. Mesophytic species such as sugar maple, yellow-poplar, white oak, overcup oak, loblolly pine, and Virginia pine from adjacent terraces and uplands may appear in the community.

Geographic distribution. The type occurs sporadically where the ranges of the two species overlap. Generally, this is a region that extends from northeastern Florida west to eastern Texas, north to southern Illinois, east through southern Ohio, and then northeast into parts of southern New England (Little 1971). In combination with other bottomland types river birch-sycamore occurs primarily along rivers and streams and occasionally on wet lake margins. The type has been reported at an elevation of 457 m (1,500 ft.) in the southern Appalachian Mountains (Allen R. Bateson 1978, personal communication) and may occur as high as 762 m (2,500 ft.).

Ecological relationships. The position of the type adjacent to rivers and streams suggests that it appears early in the establishment of floodplain vegetation and follows pioneer species such as black willow. However, either or both species may occur in the absence of a willow border (Wistendahl 1958). Seedling establishment and survival are more closely associated with flooding patterns and with the absence of competition for light from other bottomland and floodplain species than with a rigid successional sequence. Although tolerant of periods of soil saturation, both species grow best in the generally moist but periodically drained sandy alluvium of natural levees, where litter accumulation is sparse and there is direct light.

River birch may form almost pure stands along streams flooded by acidic water where a consequential increase in dissolved aluminum is toxic to associated species but not to river birch (Cribben and Ungar 1974).

The occurrence of river birch and sycamore together in numbers sufficient to be recognized as a type is probably fortuitous and dependent on seed dispersal at a time when bare soil (deposited by floods or exposed by erosion) is available for seedling establishment. Flooding kills many seedlings. River birch seed germinate in large numbers soon after dispersal in late spring or early summer, whereas sycamore seed are dispersed in the fall but germinate the following spring (Forest Service, USDA, 1948). Flooding subsequent to these times reduces seedling density of one or the other or both species.

Variants and associated vegetation. The relative proportion of each species in a given stand varies greatly. In areas affected by acid mine water drainage, the type may be composed of but six or fewer species of trees, with river birch comprising 90 percent or more of the stem density. Elsewhere, a greater mix of species (12 or more) may be found, with river birch having approximately half of the total stem density. In such stands the density of sycamore stems is generally less than 10 percent (Cribben and Ungar 1974).

Locally within any stand river-bank grape or winter grape may be abundant. Poison-ivy occurs on disturbed, open sites. Few shrubs are present, but small trees such as common (hazel) alder, American bladdernut, and American hornbeam may form a dense understory. Herbaceous plants are highly diverse and are abundant seasonally, especially spotted touch-me-not and wood-nettle.

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Silver Maple–American Elm
62

Definition and composition. Silver maple and American elm are the majority species in this type, although the proportion of either depends on the history of the stand. Major associates may include sweetgum, pin oak, swamp white oak, eastern cottonwood, sycamore, green ash, and other moist-site hardwoods, according to the region.

Geographic distribution. The type is common throughout the central forest region of the United States and in the deciduous southern portion of the Great Lakes-St. Lawrence forest region of Canada. It occurs primarily on well-drained moist sites along river bottoms and floodplains and beside lakes and larger streams. This type is only sparingly represented along the East Coast and is absent at the high elevations in the Appalachians. It is most common in the Ohio, Wabash, upper Mississippi, and Missouri river valleys of the United States and in the floodplains of southern Ontario.

Ecological relationships. Silver maple–American elm is generally regarded as a subclimax type in the portion of its range in the United States, following cottonwood and willow, and as a climax type in the portion of its range in southern Ontario, where it regenerates in willow and red-osier dogwood thickets. Small pockets may sometimes develop as pioneer succession on abandoned agricultural lands on floodplains. The type is more common on organic soils than on medium- to fine-textured mineral soils; rarely does it occur on clays and gravels.

Variants and associated vegetation. A variant, silver maple–American elm–pin oak–sweet gum, is found in sloughs and well-drained benches along major streams in southern Illinois and southern Indiana (Telford 1926). In southern Ontario the type generally consists of a mixture of silver maple, American elm, green ash, and eastern cottonwood in varying proportions. However, in the washboard swamps where high and low ground is intermingled the type often includes such species as red maple, basswood, black walnut, black cherry, black gum, hackberry, and boxelder. The understory may include willow, redberry elder, red-osier dogwood and greenbriar. The ground cover mainly consists of wood-nettle, jewelweed, poison-ivy, ferns, sedges, cardinal-flower, Joe-pye-weed, swamp milkweed, and boneset.

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Cottonwood
63

Definition and composition. Cottonwood is pure or comprises a majority of the stocking, but it is associated with other bottomland hardwoods. Eastern, plains, and swamp cottonwood are included under the type name. The chief associates in the younger stages are black and sandbar willow. Sweetgum is rare. White or green ash, silver maple, and American elm may occur in the northern extremities of the type and pecan, sycamore, and sugarberry in the southern.

Geographic distribution. The type is characteristic of the fronts or banks of all major streams in the central and southern forests. It is found along major streams of the Great Plains, but particularly within the Mississippi, Ohio, and Missouri river systems. Along the East Coast, cottonwood as a type occurs only in small groups along river and stream bottoms.

Ecological relationships. Cottonwood is a temporary, pioneer type capable of phenomenal growth. Along with the willows, it establishes itself wherever moist, bare soil is available: on newly made sandbars, front land ridges, and well-drained flats, and occasionally on abandoned fields on well drained ridges in the first bottoms. Where cottonwood and willow occur together, cottonwood outgrows willow and eventually becomes dominant unless frequent and extended flooding during the growing season covers the trees and only willow survives. Sites commonly silt in during the life of the stand, with possible elevation changes as great as 6 m (20 ft.), though the increment from any one flood may range from only 2.5 cm (1 in.) to .9 to 1.5 m (3 to 5 ft.). Cottonwoods and willow are relatively short lived and cannot regenerate under shade. Invaders in the next successional stage are sycamore, pecan, sugarberry, hackberry, river birch, green ash, American elm, silver maple, red maple, and boxelder. As soils build up and willows and cottonwoods drop out, succession in the central forest usually passes to the silver maple–American elm type or to boxelder, and in the southern forest to sycamore–sweetgum–American elm, sugarberry–American elm–green ash, or boxelder. The cottonwood type merges with the cottonwood–willow type in the Great Plains area.

Variants and associated vegetation. Common understory tree species are boxelder, sugarberry, red maple, silver maple, American elm, red mulberry, roughleaf dogwood, and swamp-privet. Undergrowth may consist of stinging nettle, pokeweed, poison-ivy, greenbrier, trumpet creeper, peppervine, dewberry, and grape. Herbs may or may not be present, depending on how dense the overstory is and how long flood waters cover the ground during the growing season.

Levee systems and stream channelization have restricted the area available for formation of the cottonwood type.

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Pin Oak–Sweetgum
65

Definition and composition. Pin oak and sweetgum form the majority of trees in the overstory, although the proportion of each varies according to geographic location and edaphic factors. Associates may include red maple, American elm, blackgum, swamp white oak, willow oak, overcup oak, bur oak, green ash, Nuttall oak, swamp chestnut oak, white oak, and shellbark and shagbark hickories.

Geographic distribution. This forest cover type occurs in the Ohio River Valley and tributaries from West Virginia through southwestern Ohio, southern Indiana, southern Illinois, Kentucky (except the eastern mountains), and in the western two-thirds of Tennessee. It extends southward in the central Mississippi River Valley from southeastern Missouri to central Arkansas and western Tennessee and through central Arkansas in the Arkansas River Valley (Telford 1926, Chapman 1942).

Ecological relationships. In broader stream valleys the type occurs on clay flats and in depressions where shallow water accumulates during the winter, and on clay ridges of first bottoms (Putnam and Bull 1932; Braun 1936,1950; Kilkus 1977). The type is rare, however, on the most poorly drained sites and does not occur where inundation is permanent. It also occurs in old fields on poorly drained, impervious wet uplands of the Illinoian till plain, but pure pin oak stands much more commonly occupy these sites, which comprise the "pin oak flats."

The pin oak–sweetgum type is an early successional stage in the regrowth of bottomland forests, although it was common in the original forests and may persist for prolonged periods on poorly drained sites (Braun 1936). Where drainage is better sweetgum will remain as a component of later successional phases whereas pin oak is the first to disappear with further successional development. In southwestern Ohio where sweetgum and red maple are abundant in the initial regrowth phase, beech follows in the intermediate phase; where pin oak is more abundant in the initial phase, white oak follows (Braun 1936). Similar patterns probably do not develop in the western and southern portions of the range of this type.

Variants and associated vegetation. The proportion of sweetgum to pin oak increases from north to south and from wetter sites to drier, and nearly pure stands of each species may occur accordingly. In central Arkansas this type may grade into sweetgum–willow oak as the southern range limit of pin oak is reached. In the north, variants include white oak–pin oak–sweetgum (an intermediate successional stage), pin oak–American elm, pin oak–red maple, red maple–American elm–sweetgum, and pure pin oak. In the lower Ohio and central Mississippi valleys, pure pin oak stands are more abundant than mixed pin oaks and sweetgum (L.S. Minckler 1978, personal communication). Shrubs and small trees, if present, may include blue beech (American hornbeam), deciduous holly (possumhaw), poison-ivy, and trumpet creeper. The herbaceous stratum is well developed only in more open stands and includes numerous sedges and grasses (Braun 1936, Voigt and Mohlenbrock 1964).

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Willow Oak–Water Oak–Diamondleaf (Laurel) Oak
88

Definition and composition. The three species together comprise a majority of the stocking, but the proportion of each may vary widely depending on site and location. The associated tree species may include Nuttall oak, red maple, green ash, sweetgum, swamp hickory, honeylocust, and, on the wetter sites, water hickory, waterlocust, and overcup oak. On better-drained areas, spruce pine loblolly pine, swamp chestnut oak, and cherrybark oak may be found in the association.

In his checklist, Little (1979) does not recognize a difference between diamondleaf oak and laurel oak, but in the past diamondleaf has been given the status of both a variety and a separate species (*Q. obtusata* Ashe.) (Sargent 1965). Those who favor separate species status point out that there are not only recognizable anatomical differences but also vast differences in site preference. Specimens first recognized as *Q. laurifolia* occur on deep, well drained soils such as the sandy banks of streams, whereas diamondleaf oak occurs on poorly drained flat sites.

Geographic distribution. The type is found in the Coastal Plain from southeastern Virginia to western Florida and through the Gulf States into the pine region of eastern Texas. It also extends into southeastern Oklahoma and southern Arkansas. The type is most abundant in Louisiana, southern Mississippi, and south central Alabama.

Ecological relationships. The type is most common on alluvial floodplains. It occupies relatively poorly drained, flat sites. Where drainage is unusually poor, diamondleaf oak makes up most of the stand, sometimes forming almost pure stands. As elevation increases and drainage improves, the willow and water oak component increases. Of the two, water oak usually occupies the somewhat better drained areas. Topographically, the type is usually located between the swamp chestnut oak–cherrybark oak type on the better-drained sites and the overcup oak–water hickory type on the poorer-drained sites. The type may also occur on terrace flats and poorly drained flatwoods sites and is often referred to as "oak glades" or "pin oak flats." It probably represents a topographic/edaphic climax, but when it is heavily cut, species such as sugarberry, green ash, American elm, and red maple may capture the site, at least temporarily.

Variants and associated vegetation. In the Mississippi River drainage, especially north of Vicksburg, the type is replaced by sweetgum–Nuttall oak–willow oak, which occupies sites similar to those of Type 88 in other drainages. In areas elsewhere than the Delta of the Mississippi, diamondleaf may gradually be replaced by Nuttall oak as the northern range of the type is approached. Some common understory components are poison-ivy, grape, Alabama supplejack (rattan), and greenbriers.

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Live Oak
89

Definition and composition. Live oak typically comprises a majority of the stocking and on coastal ridges it may be pure. Common associates are water oak and southern magnolia. On sites less well drained, sugarberry, American elm, and green ash accompany live oak.

Geographic distribution. The live oak type occurs in southern Louisiana and southwestern Mississippi on natural levees or "frontlands" and on islands within marshes and swamps.

Ecological relationships. Elevation of the frontlands where live oak is present has been determined by the flood height of the river that deposited the silt. Width of a live oak forest belt varies; at a minimum it may be only 100 m (a few hundred feet) wide or even less, and at a maximum usually under 1.6 km (less than a mile). In many places the belt becomes narrower with time as the land subsides and man-made levees prevent further flooding and silting.

The silt soils that support live oak forests represent some of the best agricultural land in the region, and much has been cleared for that purpose. Nonetheless, there are abandoned fields in the New Orleans area that have regrown to forests now about 73 years old (Bonck and Penfound 1945, Penfound and Howard 1940). The sequence is as follows: annual and perennial weeds occupy the fields for about five years, after which shrubs, especially southern bayberry (waxmyrtle) and roughleaf dogwood, begin to take over. By 25 years the shrub community approximates a young forest, but live oak seedlings begin to appear and seem destined to grow into a typical live oak forest in another 50 years.

Live oak grows on uplands but not as a majority species. Several salt domes that rise 30 to 180 m (100 to 600 ft.) above marshes in southwestern Louisiana have good soil and a climate comparable to that where live oak forests grow. However, the domes support a mixed angiosperm forest, with live oak in mixture with southern magnolia, white basswood, and American beech. Live oak here is in the majority only where planted.

Variants and associated vegetation. Variation in tree composition is due to differences in drainage that result from an elevation change of only about 1 m (a very few feet). Shrubs in the live oak forest usually include dwarf palmetto, yaupon, American elder; vines are Alabama supplejack, grape, poison-ivy, and Virginia creeper; and herbs are oak forest grass and *Tradescantia* (spiderwort).

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Swamp Chestnut Oak–Cherrybark Oak
91

Definition and composition. Swamp chestnut oak and cherrybark oak together usually constitute a majority of the stocking, but when many species are in mixture, they may comprise only a plurality. Prominent hardwood associates are the ashes (green and white) and the hickories (shagbark, shellbark, mockernut, and bitternut), as well as white oak, Delta post oak, Shumard oak, and blackgum. Sweetgum may occasionally be of high importance on first bottom ridges. Minor associates include willow oak, water oak, southern red oak, post oak, American elm, winged elm, water hickory, southern magnolia, yellow-poplar, beech, and occasionally loblolly and spruce pines.

Geographic Distribution. Small areas of the type are scattered over a large part of the South within the floodplains of the major rivers, except that of the Mississippi, where the type is rare.

Ecological relationships. The type occurs on the highest first-bottom ridges in the terraces on the best, most mature, fine sandy loam soils, and also on first-bottom ridges on a few well drained soils other than sandy loam. The site is seldom covered with standing water and rarely, if ever, overflows, though it may be hummocky and wet between hummocks. Swamp chestnut oak–cherrybark oak succeeds sycamore–sweetgum–American elm on the ridges in the terraces. Typically it is climax on older alluvium (Putnam et al. 1960). Site indexes at 50 years range from 80 to 100 for swamp chestnut oak and from 95 to 115 for cherrybark oak (Broadfoot 1976).

Variants and associated vegetation. The type most commonly occurs adjacent to the sycamore–sweetgum–American elm type and to beech–southern magnolia stands (formerly recognized as type No. 90). Among the subordinate tees and undergrowth are painted buckeye, pawpaw, American hornbeam, flowering dogwood, dwarf palmetto, Coastal Plain willow, American snowbell, southern arrowwood, possumhaw, devils walkingstick, eastern redbud, and American holly.

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Sweetgum–Willow Oak
92

Definition and composition. Sweetgum and willow oak comprise a plurality of the stocking, with sweetgum essentially the key species. Willow oak may be superseded by water oak in the southernmost range of the type. Sugarberry, green ash, American elm, and Nuttall oak are major associates, especially on slightly lower elevations. Minor associates are overcup oak, water hickory, cedar elm, eastern cottonwood, laurel oak, red maple, honeylocust, persimmon and, rarely, baldcypress. The type was formerly named sweetgum–Nuttall oak–willow oak (SAF 1954).

Geographic distribution. The type is widespread in the alluvial floodplains of major rivers in Arkansas, Louisiana, Mississippi, Alabama, eastern Missouri, and eastern Texas. Most extensive stands are in the Mississippi River delta.

Ecological relationships. The type perpetuates itself on first-bottom ridges and terrace flats, except in deep sloughs, swamps, and the lowest flats. Usually it is interspersed with the sugarberry–American elm–green ash type and the overcup oak–water hickory type. Elsewhere, heavy cutting usually increases the sweetgum component because of that species' sprouting characteristics. The sprouts grow rapidly early and continue growing well on sites where this type occurs. On transitional sites, the sweetgum–willow oak type is usually superseded by the sugarberry–American elm–green ash type. Major reasons are the oak's insufficient acorn crops, poor seedling establishment, and very slow early growth.

Variants and associated vegetation. The type becomes predominantly sweetgum on well-drained first-bottom ridges and pervious silty clays on terrace flats. It is predominantly willow oak combined with water oak on clay soils on first-bottom ridges and better drained flats and on poorly drained terrace flats. Nuttall oak dominates on well-drained, first-bottom flats. Willow oak prevails on first bottom ridges and poorly drained terrace flats. Near the Gulf Coast, laurel oak dominates. A cedar elm–water oak–willow oak variant occurs on poorly drained impervious soils on low, indistinct or flattened first-bottom ridges; this variant is also of minor importance on certain impervious terrace sites, amounting to high, shallow flats.

Understory species are sugarberry, green ash, oaks, red maple, and red mulberry. Undergrowth includes greenbrier, dwarf palmetto, and several vines—redvine, peppervine, trumpet-creeper, and poison-ivy.

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Sugarberry–American Elm–Green Ash
93

Definition and composition. The type species sugarberry, American elm, and green ash together constitute a plurality of the stocking. Hackberry replaces sugarberry in the northern part of the range. Major associates include water hickory; Nuttall, willow, water, and overcup oaks; sweetgum; and boxelder. Other associated species are cedar and winged elm, blackgum, persimmon, honeylocust, waterlocust, red and silver maple, American sycamore, and eastern cottonwood.

Geographic distribution. The type is found throughout the southern forests from east Texas to the Atlantic, from the Gulf Coast to southern Illinois. It is found within the floodplains of the major rivers.

Ecological relationships. The type is usually located in transitional areas between the sweetgum–willow oak type, which occupies higher elevations, and the overcup oak–water hickory type, which occurs at the lower elevations. lt occupies low ridges, flat, and sloughs in first bottoms; terrace flats and sloughs; and occasionally new lands or fronts. Rarely does it occur on maltreated terrace ridges. It may be found on clay or silt loam soils, and it tends to be long term in the successional scale. The type species are all shade tolerant when small and reproduce readily. All three, but especially green ash, sprout prolifically.

Variants and associated vegetation. Occasional small stands of pure green ash may occur almost anywhere within the type, but most notably on moist flats or in shallow sloughs. Stands composed predominantly of sugarberry occur on new land or front sites.

The understory commonly includes sugarberry, ash, elm, water hickory, Nuttall oak, overcup oak, red maple, roughleaf dogwood, hawthorn possumhaw, and red mulberry. Undergrowth includes several vines—trumpet-creeper, peppervine, redvine, rattan (Alabama supplejack), Carolina moonseed, Virginia creeper, grape, and poison-ivy. Herbaceous plants include bedstraw, violet, wild carrot, wild lettuce, amsonia, mint, legumes, sedge, smartweed, and false indigo. When openings are created in the stands, a heavy growth of annual grasses and cocklebur may occur.

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Sycamore–Sweetgum–American Elm
94

Definition and composition. American sycamore, sweetgum, and American elm together comprise a plurality of the stocking, but composition varies widely from mixed stands to nearly pure stands of one of the type species. The type includes the river front species-site type described by Putnam et al. (1960), which occurs on the banks or front land of major rivers in the southern forest. The most common associated species are green ash, sugarberry (and hackberry in the northern Mississippi River Valley), boxelder, silver maple, cottonwood, black willow, water oak, and pecan. This type was formerly designated sycamore–pecan–American elm (SAF 1954).

Geographic distribution. Sycamore–sweetgum–American elm occurs as scattered stands throughout the southern forest region (exclusive of Florida). This area includes the southeastern Coastal Plain (Delaware to Georgia), the Gulf Coastal Plain (Alabama to Texas and north to southern Arkansas and southeastern Oklahoma), and the Mississippi River floodplain (Louisiana to southern Missouri). The type is also present in the lower Ohio River Valley and its lower tributaries, and in the Piedmont and Cumberland plateaus, and adjacent areas.

Ecological relationships. The type occupies river fronts in the first bottoms of major rivers, the banks of smaller rivers and large creeks that flood, and occasionally branch heads and coves of small creeks. Slightly elevated sites with somewhat poorly drained to well-drained silty soils of alluvial origin characterize the river fronts (Broadfoot 1976). In small creek bottoms the type occurs on nonalluvial soils that are usually coarser textured. The soils of both kinds of sites typically are rich, with moderately good drainage, and have adequate moisture throughout the growing season. Site indexes at 50 years range from 100 to 130 for sycamore and 90 to 120 for sweetgum (Broadfoot 1976).

The type succeeds the cottonwood type on river front sites, but may pioneer on heavily cut over sites or old fields in either river bottoms or small creek bottoms. Where repeated disturbances such as floods occur, the type may represent a persistent subclimax, but the climax on these sites will be swamp chestnut oak–cherrybark oak or sweetgum–willow oak.

Variants and associated vegetation. Sycamore–pecan–American elm variant is found on river fronts in the Mississippi River Valley. On wetter sites with heavier soils in alluvial bottoms of rivers, the type becomes transitional with sweetgum–willow oak. On branch heads and coves of small creeks in the uplands the type intergrades with sweetgum–yellow-poplar. The companion types in the central forest region are river birch–sycamore and silver maple–American elm.

Some common understory components of the type include pawpaw, giant cane, and pokeweed (McKnight 1968). Vines often present are poison-ivy, grape, Alabama supplejack (rattan), greenbriers, and Japanese honeysuckle. Wood-nettle is sometimes present in moist coves and bottoms.

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Black Willow
95

Definition and composition. Black willow and other species of *Salix* together comprise a majority of the stocking. Cottonwood is the chief associate, particularly in the early stages, but green ash, sycamore, pecan, persimmon, waterlocust, American elm, baldcypress, red maple, sugarberry, boxelder, and in some areas, silver maple are invaders preceding the next successional stage.

Geographic distribution. The type is characteristic of the fronts and banks of most major streams through the central and southern forests but extends also into the northern forest. Along the East Coast, the black willow type has only minor distribution and then generally in swamps rather than in river bottoms.

Ecological relationships. Black willow is a temporary, pioneer type of very rapid growth. Along with cottonwood, it is the first to appear on newly formed sandbars and river margins, almost to the exclusion of other species. It is also frequently found in front land, sloughs, and low flats and occasionally in shallow swamps and deep sloughs throughout the first bottom. Where willow and cottonwood occur together, cottonwood outgrows willow and becomes dominant except where frequent and extended growing-season flooding covers the trees and kills the cottonwood. Sites may silt in 6 m (20 ft.) during the life of the stand, and any one flood may increase the elevation from 2.5 cm (1 in.) to 1.5 m (5 ft.).

Black willow is relatively short lived and cannot regenerate under shade. As the soils build up and the willow and cottonwoods drop out, the type is usually replaced in the central forest by the silver maple–American elm type and by boxelder; and in the southern forest by the sycamore–sweetgum–American elm type and by boxelder and, on the lower sites, by swamp-privet. The type merges with the cottonwood–willow type in the prairie-plains area.

Variants and associated vegetation. Common understory tree species are boxelder, red maple, red mulberry, swamp-privet, and planer tree (waterelm). Undergrowth may consist of buttonbush, possumhaw, poison-ivy, trumpet-creeper, redvine, and peppervine. Herbs may or may not be present, depending on length of growing season overflow and density of overstory.

Levee systems and stream channelizations have restricted the area available for formation of this type.

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Overcup Oak–Water Hickory
96

Definition and composition. Overcup oak and water hickory together make up a majority of the stocking. Major associates are green ash, sugarberry, American elm, waterlocust, red maple, and Nuttall oak. Willow oak, persimmon, and cedar elm are minor associates.

Geographic distribution. The type occurs in the floodplain forests of the Gulf and south Atlantic states and also in Tennessee and southern Illinois. The most extensive areas occupied are backwater basins of the principal rivers.

Ecological relationships. The type usually occurs in areas where water stands into the growing season–lowlying, poorly drained flats with clay or silty clay soils. It also occurs in sloughs in the lowest backwater basins and on low ridges with clay soils that are subject to late spring inundation. Site quality is usually quite poor and most species cannot survive where this type exists. Where drainage is improved, the type may revert to sugarberry–American elm–green ash. Overcup oak reproduces more consistently than other oaks; its good seed crops are frequent and its acorns, which seem to be less desirable to wildlife than most, receive some protection from the water. Water hickory is a prolific sprouter and reproduces in this fashion when the stand is cut. Both overcup oak and water hickory are among the last tree species to leaf out in the growing season and thus are less subject to the mortality that occurs when seedlings or sprouts in leaf are covered by standing water.

Variants and associated vegetation. Nearly pure water hickory stands or pure overcup oak stands can be found representing the type. Sometimes there is clear demarcation between the overcup oak–water hickory and the sugarberry–American elm–green ash type, but usually the two types mix in a transitional zone.

Understory includes the water hickory, overcup oak, and occasionally Nuttall oak, green ash, sugarberry, roughleaf dogwood, swamp-privet, and planertree (water-elm). Undergrowth includes buttonbush and numerous vines—redvine, peppervine, trumpet creeper, and poison-ivy. Because of the depth and duration of standing water in this type, associated herbaceous plants are few. Following cutting or partial opening of the stands, heavy growth of annual grasses and cocklebur may occur.

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Baldcypress
101

Definition and composition. Baldcypress is pure or comprises a majority of the stocking. Its main associates are water tupelo in the alluvial floodplains or swamp tupelo in the swamps and estuaries of the Coastal Plain. Other associates are pondcypress, black willow and, occasionally, swamp cottonwood, red maple, Atlantic white-cedar, American elm, green ash, pumpkin ash, Carolina ash, waterlocust, redbay, common persimmon, overcup oak, and water hickory.

Geographic distribution. The type occurs intermittently through the Coastal Plain from southern Delaware to south Florida, and west to southeastern Texas almost to the Mexican border. Inland, it occurs along the many streams of the coastal plains and northward through the Mississippi Valley to southeastern Oklahoma, southeastern Missouri, southern Illinois, and southwestern Indiana (Fowells 1965).

Ecological relationships. The baldcypress species is unusual in form, shape, and habitat requirements. Sites are usually characterized by frequent prolonged flooding. Floodwaters may be 3 m (10 ft.) deep or more and may be stagnant or may flow at rates up to 7 km (4 mi.) per hour. Cypress knees are common on trees on most sites, but are usually absent where the floodwater remains at a constant level or where there is no flooding. It is not clear what role cypress knees play in aeration of the root system, but it is known that they exchange oxygen and carbon dioxide with their surroundings under normal atmospheric conditions. Thus it appears that they may be beneficial as an aeration organ but not critical to tree survival.

Baldcypress shows adaptations to flooding similar to those of water and swamp tupelos, the main associates in the type. Under prolonged flooding newly adapted roots develop near the base of the tree. The new roots are more succulent, larger in diameter, and less branched than roots of cypress grown in moist well-aerated soils. Newly adapted roots of tupelos have been observed to oxidize their rhizosphere in floodwaters (Hook et al. 1971). Cypress roots also show evidence of oxidation at depths up to 1.2 m (4 ft.), thus providing oxygen to active root tips and facilitating nutrient uptake from otherwise highly reduced soil environment. Baldcypress grows along the estuaries near the coast, but apparently cannot tolerate salinities above 0.89 percent salt (Montz and Cherubini 1973).

Cypress, highly prized for its lumber, was so heavily exploited during the first half of the 20th century that there was much concern for its future. All recent evidence, however, suggests a general replacement by second growth (Sternitzke 1972).

Variants and associated vegetation. The type has one major variant, baldcypress–pondcypress (Langdon 1958). Where the two species occur together it is difficult and sometimes impossible to tell them apart. These two intermingle in varying proportions in the lower coastal plains from southeastern Virginia to eastern Louisiana. The baldcypress type has only a few shrub associates and these vary widely. The most prominent in south Florida are common buttonbush, swamp (stiffcornel) dogwood, and Walter viburnum. In contrast, the most common associates in North Carolina are the coast leucothoe, Carolina rose, poison-sumac, swamp dogwood, and possumhaw viburnum. In addition, ferns, vines, epiphytes, alligator-weed, and duckweeds are present.

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Baldcypress–Tupelo
102

Definition and composition. Baldcypress together with water tupelo or swamp tupelo comprises the majority of the stocking. On deep alluvial swamps, the common associates are red maple, black willow, Carolina ash, pumpkin ash, swamp cottonwood, planertree (water-elm), and waterlocust. In the shallower margins, overcup oak, water hickory, American elm, green ash, Nuttall oak, laurel oak, sweetgum, persimmon, and sweetbay are also present. In Coastal Plain swamps, red maple, black willow, redbay, sweetbay, pondcypress, slash pine, and loblolly pine are found. Ogeechee tupelo is an associate in southwestern Georgia and northern Florida. Atlantic white-cedar and pond pine are also present in some acid, peaty swamps of the Atlantic Coastal Plain.

Geographic distribution. The type occurs in the southern Coastal Plain, particularly on the seaward margins, from southeastern Texas to Maryland, excluding the lower third of the Florida peninsula. It is also present in the Mississippi River bottom and along the lower reaches of its tributaries north to southern Illinois.

Ecological relationships. The type is always found on very wet sites where, in years of normal rainfall, surface water stands well into or throughout the growing season. These include swamps, deep sloughs, very low, poorly drained flats of the major river floodplains, swamps of tidal estuaries, margins of coastal marshes and the deeper, more extensive landlocked depressions of the Coastal Plain (Penfound 1952).

Soils of the alluvial bottoms are mineral soils and usually range in texture from silt loam to almost pure clay; surface soil pH varies from moderately acid to slightly alkaline. Coastal swamps and depressions of the Coastal Plain usually have a surface of muck or shallow peat. The mineral fraction of the soil may range from fine sand to clay, and soil pH ranges from moderately to strongly acid.

Stand makeup is strongly influenced by site as well as by cutting. Water tupelo cannot survive where soil acidity is high or surface water brackish. Consequently, it is almost completely restricted to alluvial floodplains and is replaced by swamp tupelo on colluvial soils of the Coastal Plain and in coastal swamps. Swamp tupelo also occurs in mixture with baldcypress and water tupelo around the edges of alluvial swamps where maximum water depth is less than 0.6 m (about 2 ft.). Baldcypress and water tupelo are most tolerant of complete inundation and advance into the deepest sites when water depth is reduced during periodic droughts, particularly around quiet ponds and lakes. In shallow swamps, water and swamp tupelo regenerate more successfully than baldcypress because of greater seed production and somewhat faster early growth. Here, following heavy cutting, the type usually reverts to water or swamp tupelo (Putnam et al. 1960). Regeneration of swamp tupelo and water tupelo by stump sprouts is also of major importance in cut over stands; sprouting of baldcypress is minor.

No clear succession has been observed in this type and, barring aggradation, it is considered permanent and is held in this stage by prolonged periods of deep flooding (Wells 1928). The relative shade tolerance of baldcypress and water tupelo has not been clearly established; both are rated intolerant and both endure heavy stocking in even-aged stands. When in association with baldcypress, water tupelo is usually the younger component, suggesting the greater tolerance of the latter and a possible trend towards pure stands of that species without periodic disturbance.

Variants and associated vegetation. Small, pure stands of baldcypress are scattered throughout the type. Regeneration of baldcypress is very uncertain, however, and stands usually revert to tupelo following heavy cutting.

In the deep swamps and under dense stands, undergrowth, sparse because of low light intensity and long hydroperiods, is limited to a few shrubs and some aquatic herbs. Mosses and lichens are common on the lower exposed portions of the tree trunks. Spanish moss often drapes the crowns. In shallow swamps and along the fringes of the deep swamps, a wide variety of wet-site shrubs may commonly occur: buttonbush, swamp-privet, Virginia sweetspire (Virginia-willow), swamp cyrilla, buckwheat-tree, stiffcornel (swamp) dogwood, fetterbush lyonia, leucothoe, dahoon, yaupon, southern bayberry, possumhaw, swamp rose, and poison-sumac. Woody vines that may be common include greenbriers, Alabama supplejack, southeast decumaria, crossvine, peppervine, and poison-ivy.

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Water Tupelo–Swamp Tupelo
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Definition and composition. Where the type is most extensive, water tupelo is pure or provides a majority of the basal area stocking. On certain more limited sites, however, swamp tupelo tends to take the place of water tupelo. On some sites the two type species mix. Common associates of water tupelo where flooding is deep are baldcypress, red maple, black willow, Carolina ash, pumpkin ash, swamp cottonwood, planer tree (water-elm), and waterlocust. In shallow water, swamp tupelo, overcup oak, water hickory, American elm, green ash, Nuttall oak, laurel oak, sweetgum, persimmon, and sweetbay are also present. Common associates of swamp tupelo in addition may include pondcypress, redbay, sweetbay, slash pine, and loblolly pine. Ogeechee tupelo is an associate in southeastern Georgia and northern Florida. Atlantic white-cedar and pond pine are also associates in some acid, peaty swamps of the Atlantic Coastal Plain. The type formerly was named water tupelo.

Geographic distribution. The type occurs in the southern Coastal Plain from southeastern Texas to southern Florida and northward to southeastern Virginia. It also occurs in the Mississippi River bottom and the lower reaches of its tributaries and in bottomlands of the Tennessee River in Alabama. The water tupelo component is nearly absent from most of the Florida peninsula and the southeastern corner of Georgia.

Ecological relationships. The type is always found on very wet sites where, in years of normal rainfall, surface water stands well into or throughout the growing season. Stands of water tupelo are restricted to deep swamps, sloughs, and low flats of the alluvial floodplains, whereas those of swamp tupelo occur in upland swamps and ponds of the Coastal Plain and in slightly brackish swamps of coastal estuaries and marsh borders (Penfound and Hathaway 1938). Mixtures occur along the shallow borders of alluvial swamps and flats and where such sites grade into upland swamps. Water tupelo sites are characterized by deeper and longer periods of flooding than swamp tupelo sites, and by higher pH and silt-plus-clay content but lower organic matter content of the surface soil (Klawitter 1962).

The type is permanent on most sites because of annual flooding. Relatively rapid soil aggradation over limited areas in alluvial bottoms undoubtedly does occur. The resulting improvement in soil aeration should favor changes in composition following the sequence observed in southern bottoms on sites with increasing drainage (Putnam et al. 1960).

Variants and associated vegetation. There are no common variations of this type. Uncut stands of water or swamp tupelo are typically very densely stocked. In water tupelo stands with normally deep flooding, undergrowth is often limited to scattered shrubs with some aquatic herbs. Epiphytic mosses and lichens are common on the exposed tree trunks, particularly the lower and north-facing portions, and the crowns may be draped with Spanish moss. Wet-site shrubs become more abundant along shallow margins of the swamps or in stand openings; species occurring widely and frequently include buttonbush, swamp-privet, Virginia sweetspire (Virginia-willow), swamp dogwood, swamp cyrilla, leucothoe, possumhaw, swamp rose, and poison-sumac. Woody vines frequently occurring along the shallow swamp margins are greenbriers, Alabama supplejack, southeast decumaria, crossvine, peppervine, and poison-ivy.

In the usually shallower upland swamps where swamp tupelo is dominant there are additional woody plants not common to the alluvial swamps. These include such species as buckwheat-tree, dahoon, yaupon, southern bayberry, fetterbush lyonia, summersweet clethra (sweet pepperbush), and several hawthorns.

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Sweetbay–Swamp Tupelo–Redbay
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Definition and composition. Combinations of sweetbay with swamp tupelo, redbay, or both provide a majority of the stocking, and locally any one of the three may possess a plurality. A great many species that grow on moist to wet sites may be associated with this type, depending upon geographic location, site and stand history. Common hardwoods include red maple, black tupelo, loblolly-bay, sweetgum, water oak, laurel oak, yellow-poplar, American holly, Carolina ash, southern magnolia, and flowering dogwood. Associated conifers include baldcypress, pondcypress, slash pine, longleaf pine, loblolly pine, pond pine, and Atlantic white-cedar.

Geographic distribution. The type is found throughout the southern Coastal Plain from Maryland and southeastern Virginia to southeastern Texas. It is most extensive in the lower Coastal Plain. Individual stands of this type are commonly limited in area, although locally they may predominate.

Ecological relationships. The type occurs on sites where the soil is normally saturated, or at least moist, throughout the growing season. Surface flooding also occurs on some sites, but it does not persist through the growing season. Sites include branch heads; the narrow bottoms of small perennial or intermittent streams or branches; pocosins; and poorly drained upland depressions in the Coastal Plain such as small ponds, peat bogs, and the borders of swamps.

Soils are sandy in texture and predominantly colluvial in origin, although narrow alluvial floodplains occur in stream bottoms. The wetter sites are consistently very acid, pH 4.0-4.5, and relatively sterile, whereas sites with better drainage are frequently very productive. Stands on more acid, sterile sites generally contain a high proportion of hardwood evergreens, such as redbay, sweetbay, and loblolly-bay, as well as the conifers pond pine and Atlantic white-cedar (Monk 1966).

Deep flooding in ponds and around swamp borders favors swamp tupelo, pondcypress, baldcypress, and red maple. Improved drainage increases representation of such species as black tupelo, yellow-poplar, sweetgum, American holly, and southern magnolia. Changes in soil drainage and related properties are often abrupt, and over short distances stands may contain species representative of both the more deeply flooded swamps and the surrounding uplands. The type is permanent because of persistent soil saturation.

Despite the usual wetness of the sites, fires frequently spread into stands from the surrounding uplands. Fire during drought can be very destructive because of the flammable nature of the peat accumulations and the evergreen foliage of many species. In peaty bogs and shallow swamps, Atlantic white-cedar may dominate if the peat is too wet to burn. Shallow burns favor pond pine, but stands may revert to pondcypress–swamp tupelo after deep burns (Wells 1942). Fires on better-drained sites with mineral soils increase the representation of shade-intolerant species such as slash and longleaf pine, yellow-poplar, and sweetgum, but selective cutting of these species has kept their numbers low (Gemborys and Hodgkins 1971). Recurrent fires on any site tend to develop evergreen shrub or grass-sedge-rush communities.

Variants and associated vegetation. The type itself exhibits such wide variation that there is no single common variant. Undergrowth is both abundant and diverse. Evergreen shrubs and small trees are prevalent, particularly on the poorly drained acid sites. Common species include buckwheat tree, swamp cyrilla, southern bayberry, odorless bayberry, dahoon, yaupon, large gallberry, inkberry, coast leucothoe, fetterbush and staggerbush lyonia, summersweet clethra (sweet pepperbush), and switchcane. Common deciduous shrubs are Virginia sweetspire (Virginia-willow), hazel alder, swamp dogwood, red chokeberry, poison-sumac, American snowbell, possumhaw viburnum, and numerous ericaceous species.

Greenbriers, muscadine grape, poison-ivy, Japanese honeysuckle, Virginia creeper, southeast decumaria and climbing hempweed are common perennial vines. Herbaceous species occurring within this type are incompletely catalogued and are too numerous and variable to list. Some relatively common and characteristic representatives, however, are ferns, mosses, pitcher plants, pipeworts, yellow-eyed grasses, and sedges.

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References Cited

Bonck, J., and W.T. Penfound. 1945. Plant succession on abandoned farmland in the vicinity of New Orleans, Louisiana. American Midland Naturalist 33:520-529.

Braun, E.L. 1936. Forests of the Illinoian till plain of southwestern Ohio. Ecological Monographs 6:89-149.

Broadfoot, W.M. 1976. Hardwood suitability for and properties of important Midsouth soils. U.S. Department of Agriculture, Forest Service Research Agricultural Handbook 486. 52 p.

Chapman, A.G. 1942. Forests of the Illinoian till plain of southeastern Indiana. Ecology 23:189-198.

Cribben, L.D., and I.A. Ungar. 1974. River birch (*Betula nigra* L.) communities of southeastern Ohio. Ohio Biological Survey Notes 8, Ohio State University, Columbus. 37 p.

Forest Service, U.S. Department of Agriculture. 1948. Woody-plant seed manual. U.S. Department of

Agriculture Miscellaneous Publication 654. 416 p.

Fowells, H.A. (compiler). 1965. Silvics of forest trees of the United States. U.S. Department of Agriculture, Forest Service Agriculture Handbook 271. 762 p.

Gemborys, S.R., and E.J. Hodgkins. 1971. Forests of small stream bottoms in the Coastal Plain of southwestern Alabama. Ecology 52:70-84.

Hook, D.D., C.L. Brown, and P.P. Kormanik. 1971. Inductive flood tolerance in swamp tupelo (*Nyssa sylvatica* var. *biflora* [Walt.] Sarg.). Journal of Experimental Botany 22(70):78-89.

Kilkus, P.A. 1977. Cover typing a proposed research natural area for southern Illinois, with an in-depth approach to method evaluation. M.S. Thesis, Southern Illinois University, Carbondale. 102 p.

Klawitter, R.A. 1962. Sweetgum, swamp tupelo and water tupelo sites in a South Carolina bottomland forest. Ph.D. Thesis, Duke University, Durham, NC. 175 p.

Langdon, O.G. 1958. Silvical characteristics of baldcypress. U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. Paper 94. 7 p.

Little, E.L., Jr. 1971. Atlas of United States trees, vol. 5. Florida. U.S. Department of Agriculture, Forest Service Miscellaneous Publication 1361.

Little, E.L., Jr. 1979. Checklist of United States trees (native and naturalized). U.S. Department of Agriculture, Forest Service Agricultural Handbook 541. 375 p.

McKnight, J.S. 1968. Ecology of four hardwood species. Proceedings of the Louisiana State University Forestry Symposium 17:99-116.

Monk, C.D. 1966. An ecological study of hardwood swamps in north central Florida. Ecology 47:649-654.

Montz, G.N., and A. Cherubini. 1973. An ecological study of a baldcypress swamp in St. Charles Parish, Louisiana. Castanea 38:378-386.

Penfound, W.T. 1952. Southern swamps and marshes. Botanical Review 19:413-446.

Penfound, W.T., and E.S. Hathaway. 1938. Plant communities in the marshlands of southeastern Louisiana. Ecological Monographs 8:1-56.

Penfound, W.T., and J.A. Howard. 1940. A phytosociological study of an evergreen oak forest in the vicinity of New Orleans, Louisiana. American Midland Naturalist 23:165-174.

Putnam, J.A., and H. Bull. 1932. The trees of the bottomlands of the Mississippi River delta region. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station Occasional Paper 27. 207 p.

Putnam, J.A., G.M. Furnival, and J.S. McKnight. 1960. Management and inventory of southern hardwoods. U.S. Department of Agriculture, Forest Service Agriculture Handbook 181. 102 p.

Sargent, C.S. 1965. Manual of the trees of North America. Dover Publications, Inc., New York. 934 p.

Society of American Foresters (SAF). 1954. Forest covertypes of North America (exclusive of Mexico). Society of American Foresters, Washington, DC. 67 pp.

Sternitzke, Herbert S. 1972. Bald cypress: endangered or expanding species? Economic Botany 26:130-134.

Telford, C.J. 1926. Third report on a forest survey of Illinois. Illinois Natural History Survey Bulletin 16: 1-102.

Voigt, J.W., and R.H. Mohlenbrock. 1964. Plant communities of southern Illinois. Southern Illinois University Press, Carbondale. 202 p.

Wells, B.W. 1928. Plant communities of the Coastal Plain of North Carolina and their successional relations. Ecology 9:230-242.

Wells, B.W. 1942. Ecological problems of the southeastern United States Coastal Plain. Botanical Review 8:533-561.

Wistendahl, W.A. 1958. The floodplain of the Raritan River, New Jersey. Ecological Monographs 28:129-153.

Appendix B
Common and Scientific Names of Plant and Tree Species

Common name	**Scientific name**
Plants	
America pokeweed (see pokeberry)	*Phytolacca americana*
American wormseed (see Mexican tea)	*Chenopodium ambrosioides*
Annual ragweed (see ragweed)	*Ambrosia artemisifolia*
Aquatic milkweed (see milkweed)	*Asclepias perennis*
Autumn olive	*Elaeagnus umbellata*
Bahia grass	*Paspalum notatum*
Beakrush (see millet beakrush)	*Rhynchospora miliacea*
Beggartick (see small-fruit beggartick)	*Bidens mitis*
Bermuda grass	*Cynodon dactylon*
Blackberry	*Rubus argutus*
Boneset	*Eupatorium perfoliatum*
Brazilian pepper tree	*Schinus terebinthifolius*
Broomsedge	*Andropogon virginicus*
Bugleweed	*Lycopus* spp.
Burnweed	*Erechtites hieracifolia*
Bur-reed (burreed)	*Sparganium* spp.
Bushy beardgrass (bushy bluestem)	*Andropogon glomeratus*
Cane	*Arundinaria gigantea*
Cattail	*Typha latifolia*
Chain-fern	*Woodwardia* spp.
Chinese bushclover	*Lespedeza cuneata*
Chinese tallow	*Triadica sebiferum*
Cocklebur	*Xanthium* spp.
Coffeeweed	*Sesbania macrocarpa*
Cogongrass	*Imperata cylindrica*
Common carpetgrass (see Southern carpetgrass)	*Axonopus fissifolius*
Coral honeysuckle	*Lonicera sempervirens*
Crabgrass	*Digitaria* spp.
Dewberry	*Rubus hispidus*
Dog fennel (see small dogfennel)	*Eupatorium capillifolium*
Falsenettle (see small-spike falsenettle)	*Boehmeria cylindrica*
Fern, various species	*Osmunda* spp., *Thelypteris* spp.
Fescue	*Festuca* spp.
Florida pokeweed	*Phytolacca americana* var. *rigida*
Geranium (see purple crane's-bill geranium)	*Geranium carolinianum*
Golden club	*Orontium aquaticum*
Goldenrod	*Solidago* spp.
Goldenweed (see groundsel)	*Packera aureus*
Groundsel (see goldenweed)	*Packera aureus*
Hairlike mock bishop-weed (see mock bishop-weed, herbwilliam)	*Ptilimnium capillacium*
Herbwilliam (see hairlike mock bishop-weed, mock bishop-weed)	*Ptilimnium capillacium*
Honeysuckle, (Japanese)	*Lonicera japonica*
Horseweed	*Conzya canadensis*
Japanese climbing fern	*Lygodium japonicum*
Japanese privet	*Ligustrum japonicum*
Johnson grass	*Sorghum halepense*

Common name	**Scientific name**
Kudzu	*Pueraria lobata*
Licorice Weed	*Scoparia dulcis*
Lizard's tail	*Saururus cernuus*
Melaleuca	*Melaleuca leucadendron*
Mexican tea (see American wormseed)	*Chenopodium ambrosioides*
Mexican water-hemlock (see water-hemlock)	*Cicuta maculata*
Milkweed (see aquatic milkweed)	*Asclepias perennis*
Millet beakrush (see beakrush)	*Rhynchospora miliacea*
Mock bishop-weed (see hairlike mock bishop-weed, herbwilliam)	*Ptilimnium capillacium*
Morning glory	*Ipomoea* spp.
Multiflora rose	*Rosa multiflora*
Nutsedge	*Cyperus* spp.
Panic grass	*Panicum* spp.
Peruvian seedbox (see primrose willow)	*Ludwigia peruviana*
Pickerel weed (see pickerelweed)	*Pontederia cordata*
Pickerelweed (see pickerel weed)	*Pontederia cordata*
Pineland pimpernel (see water pimpernil)	*Samolus valerandi* var. *parviflorus*
Pokeberry (see American pokeweed)	*Phytolacca americana*
Poorjoe	*Diodia teres*
Primrose willow (see Peruvian seedbox)	*Ludwigia peruviana*
Purple crane's-bill geranium (see geranium)	*Geranium carolinianium*
Ragweed	*Ambrosia* spp.
Rough button-weed	*Diodia radula*
Sericea lespedeza	*Lespedeza cuneata*
Sheathed flatsedge	*Cyperus haspan*
Shiny spikegrass (see spikegrass, shiny wood-oats)	*Chasmanthium nitidum*
Shiny wood-oats (see shiny spikegrass, spikegrass)	*Chasmanthium nitidum*
Sicklepod	*Cassia obtusifolia*
Small dogfennel (see dog fennel)	*Eupatorium capillifolium*
Small-fruit beggartick (see beggartick)	*Bidens mitis*
Small-spike falsenettle (see falsenettle)	*Boehmeria cylindrica*
Smartweed	*Polygonum* spp.
Southern carpetgrass (see common carpetgrass)	*Axonopus affinis*
Southern crabgrass	*Digitaria ciliaris*
Spikegrass (see shiny spikegrass, shiny wood-oats)	*Chasmanthium nitidum*
Sumac, poison	*Toxicodendron vernix*
Sumac, smooth	*Rhus glabra*
Sumac, winged	*Rhus copallina*
Sunflower	*Helianthus* spp.
Swamplily	*Crinium americanum*
Sweet broom	*Scoparia dulcis*
Sweet clover	*Melilotus* spp.
Trumpet creeper	*Campsis radicans*
Vasey grass	*Paspalum urvillei*
Vetch	*Vicia* spp.
Water-hemlock (see Mexican water-hemlock)	*Cicuta maculata*
Water pimpernil (see pineland pimpernel)	*Samolus valerandi* var. *parviflorus*
Wild grape	*Vitis* spp.
Wild onion	*Allium* spp.
Winter vetch	*Vicia villosa*
Wooly croton	*Croton capitatus*

Common name	**Scientific name**
Trees	
American beech	*Fagus grandifolia*
American elm	*Ulmus americana*
American holly	*Ilex opaca*
American hornbeam	*Carpinus caroliniana*
Baldcypress	*Taxodium distichum*
Bitter pecan (see water hickory)	*Carya aquatica*
Black cherry	*Prunus serotina*
Blackgum	*Nyssa sylvatica*
Black walnut	*Juglans nigra*
Black willow	*Salix nigra*
Boxelder	*Acer negundo*
Buckthorn bumelia (buckthorn bully)	*Sideroxylon lycioides*
Bur oak	*Quercus macrocarpa*
Buttonbush	*Cephalanthus occidentalis*
Carolina ash	*Fraxinus caroliniana*
Cedar elm	*Ulmus crassifolia*
Cherrybark oak	*Quercus pagoda*
Common persimmon	*Diospyros virginiana*
Dahoon	*Ilex cassine*
Deciduous holly	*Ilex decidua*
Delta post oak	*Quercus stellata* var. *mississippiensis*
Eastern cottonwood	*Populus deltoides*
Eastern hophornbeam	*Ostrya virginiana*
Fir	*Abies* sp.
Florida maple	*Acer barbatum*
Flowering dogwood	*Cornus florida*
Green ash	*Fraxinus pennsylvanica*
Hackberry	*Celtis occidentalis*
Hawthorn	*Crataegus* spp.
Honeylocust	*Gleditsia triacanthos*
Laurel (diamondleaf) oak	*Quercus laurifolia*
Live oak	*Quercus virginiana*
Loblolly bay	*Gordonia lasianthus*
Nuttall oak	*Quercus nuttallii* (current accepted nomenclature is *Q. texana*)
Ogeechee tupelo	*Nyssa ogeche*
Overcup oak	*Quercus lyrata*
Pawpaw	*Asimina triloba*
Pin oak	*Quercus palustris*
Pondcypress	*Taxodium distichum* var. *nutans*
Possumhaw	*Ilex decidua*
Pumpkin ash	*Fraxinus profunda*
Red bay	*Persea borbonia*
Red mulberry	*Morus rubra*
River birch	*Betula nigra*
Rough-leafed dogwood	*Cornus drummondii*
Sandbar willow	*Salix exigua*
Sassafras	*Sassafras albidum*
Shagbark hickory	*Carya ovata*
Shellbark hickory	*Carya laciniosa*
Shumard oak	*Quercus shumardii*
Silver maple	*Acer saccharinum*

Common name	**Scientific name**
Slippery elm	*Ulmus rubra*
Southern magnolia	*Magnolia grandiflora*
Spruce	*Picea* sp.
Sugarberry	*Celtis laevigata*
Swamp bay	*Persea palustris*
Swamp black gum (see swamp tupelo)	*Nyssa sylvatica* var. *biflora*
Swamp chestnut oak	*Quercus michauxii*
Swamp cottonwood	*Populus heterophylla*
Swamp dogwood	*Cornus foemina*
Swampprivet	*Forestiera accuminata*
Swamp red maple	*Acer rubrum*
Swamp tupelo (see swamp black gum)	*Nyssa sylvatica* var. *biflora*
Swamp white oak	*Quercus bicolor*
Sweet bay	*Magnolia virginiana*
Sweetgum	*Liquidambar styraciflua*
Sweet pecan	*Carya illinoensis*
Sycamore	*Platanus occidentalis*
Water elm	*Planera aquatica*
Water hickory (see bitter pecan)	*Carya aquatica*
Waterlocust	*Gleditsia aquatica*
Water oak	*Quercus nigra*
Water tupelo	*Nyssa aquatica*
White ash	*Fraxinus americana*
White oak	*Quercus alba*
Willow oak	*Quercus phellos*
Winged elm	*Ulmus alata*
Yellow poplar	*Liriodendron tulipifera*

Appendix C

Partial List of Seed and Seedling Suppliers

SEED

Alabama
International Forest Seed Company
P.O. Box 490
Odenville, AL 35120
(800) 231-8079 in Alabama
(800) 633-4506 out of state
Fax: (205) 629-6671
Web page: http://issco.linnaeus.com

Arkansas
Barron’s Inc.
1864 Ouachita 67
Camden, AR 71701

Florida
Matt Buchanan
Route 1, Box 52
Mayo, FL 32066

Georgia
C.P. Daniels, Inc.
P.O. Box 119
Waynesboro, GA 30830
(800) 822-5681
Fax: (706) 554-4424
Web page : www.burke.net/cpdaniel
E-mail: ctdan@burke.net

Southern Seed Company
P.O. Box 340
Baldwin, GA 30511
(706) 778-4542
Fax: (706) 776-2736

Kentucky
Lassiter Enterprises
496 Shady Lane
Midway, KY 40347-9740

Louisiana
Louisiana Forest Seed Company
303 Forestry Road
LeCompte, LA 71346
(318) 443-5026
Fax: (318) 487-0316
E-mail: lfsco@popalex1.linknet.net

Mississippi
William H. Brown, Jr.
Forestry Consultant
46 Whispering Pines Road
Natchez, MS 39120

Missouri
Lovelace Seeds, Inc.
1187 Brownsmill Rd.
Elsberry, MO 63343
(573) 898-2103
Fax: (573) 898-2855
Web page: www.inweb.net/~lovelace
E-mail: lovelace@inweb.net

North Carolina
Mountain Farms, Inc.
307 #9 Road
Fairview, NC 28730
(828) 628-4709
Fax: (800) 393-3646

South Carolina
Thomas Caverly
P.O. Box 1223
Orangeburg, SC 29116

Tennessee
Don Marcum
Route 1, Box 410
Spencer, TN 38585

West Tennessee Forest Seed Co.
440 Joyner’s Hill Road
Bells, TN 38006
(901) 772-4213
Mobile phone: (901) 548-4043
Fax: (901) 772-7795

SEEDLINGS

STATE FORESTRY NURSERIES

Alabama
E.A. Hauss Nursery
Route 3, Box 322
Atmore, AL 36502

Arkansas
Arkansas Forestry Commission
Baucum Nursery
1402 Highway 391 North
North Little Rock, AR 72117
(501) 945-3345
Fax: (501) 945-1755

Georgia
Flint River Nursery
9850 Riveroad
Byromville, GA 31007
(912) 268-7308
Fax: (912) 268-1819

Walker Nursery
HC01, Box 217
Reidsville, GA 30453-9408
(912) 557-6821

Illinois
Mason Nursery
17855 North County Road 240 East
Topeka, IL 61567
(309) 535-2185
Fax: (309) 535-3286

Union Nursery
3520 State Rd.
Jonesboro, IL 62652
(618) 833-6125
Fax: (618) 833-8123

Kentucky
Morgan County Nursery
438 Tree Nursery Rd.
West Liberty, KY 41472
(606) 743-3511
Fax: (606) 743-1999

John R. Rhody Nursery
P.O Box 97
Gilbertsville, KY 42044
(502) 362-8331
Fax: (502) 362-7512

Louisiana
Columbia Nursery
P.O. Box 1388
Columbia, LA 71418
(318) 649-7463
Fax: (318) 649-5628

Jeane Farms
11627 Highway 4
Castor, LA 71016
(318) 544-8501

Mississippi
Mississippi Forestry Commission
90 Highway 51
Winona, MS 38967
(601) 283-1456
Fax: (601) 283-4097
E-mail: hardwood@network-one.com

Missouri
George O. White Nursery
14027 Shafer Road
Licking, MO 65542
(573) 674-3229
Fax: (573) 674-4047

North Carolina
Claridge Nursery
762 Claridge Nursery Road
Goldsboro, NC 27530
(919) 731-7988
Fax: (919) 731-7993

Edwards Nursery
701 Sanford Drive
Morganton, NC 28655
(828) 438-6270
Fax: (828) 437-2517

Coastal Plain Conservation Nursery
3067 Conners Drive
Edenton, NC 27932
(252) 482-5707
Fax: (252) 482-4987

Oklahoma
Forestry Division Nursery
830 Northeast 12th Avenue
Goldsby, OK 73093
(405) 288-2385
Fax: (405) 288-6326

South Carolina
South Carolina Forestry Commission
P.O. Box 21707
Columbia, SC 29221
(803) 737-8800

Tennessee
Pinson Nursery
P.O. Box 120, Ozier Road
Pinson, TN 38366
(901) 988-5221
Fax: (901) 426-0817

Texas
Indian Mound Nursery
P.O. Box 617
Alto, TX 75925-0617
(409) 858-4202
Fax: (409) 858-4303
E-mail: imn@inu.net

Virginia
Augusta Forestry Center
P.O. Box 160
Crimora, VA 24431
(540) 363-7000

New Kent Forestry Center
11301 Pocahontas Trail
Providence Forge, VA 23140
(804) 966-2201
Fax: (804) 966-9801

State of Virgina Forestry
Web page: http://state.vipnet.org/dof/

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P.O. Box 752
Auburn, AL 36830

International Paper
Alabama Supertree Nursery
264 County Road 888
Selma, AL 36701
(800) 222-1280 or (205) 872-5452
Fax: (334) 872-2358

Arkansas

International Paper
Fred C. Gragg Supertree Nursery
Route 2, Box 23
Bluff City, AR 71722
(800) 222-1270
Fax: (870) 685-2825

Weyerhauser
Magnolia Regeneration Center
2960 Columbia 11 East
Magnolia, AR 71753
(800) 736-9330 or (800) 221-5452
Fax: (870) 234-7918

Florida

Apalachee Native Nursery
Route 3 Box 156
Lloyd, FL 32344
(850) 997-8976
Fax: (850) 342-1216

American Native Products
P.O. Box 549
Scottsmoore, FL 32775
(407) 383-1967 or (407) 267-4176
Fax: (407) 383-4150

Central Florida Lands and Timber
Nursery Division
Route 1, Box 899
Mayo, FL 32066
(904) 294-1211
Fax: (904) 294-3416
E-mail: cflat@alltel.net

Central Florida Native Flora, Inc.
P.O. Box 1045
San Antonio, FL 33576-1045
(904) 588-3687

Coastal Revegetation
1050 South Federal Highway
Delray Beach, FL 33483
(407) 495-0198

Creative Native
P.O. Box 713
Perry, FL 32347
(850) 584-3571

Dan’s Native Nursery
2325 Lake Easy Road
Babson Park, FL 33827

Ecoshores, Inc.
3869 South Nova Road
Port Orange, FL 32127
(904) 767-6232
Fax: (904) 756-9895

Florida Natives Nursery, Inc.
5121 Ehrlich Road, Suite 103A
Tampa, FL 33624
(813) 264-5765

Gone Native Nursery
P.O. Box 1122
Jensen Beach, FL 34958-1122
(407) 334-1643 or (407) 283-8420

Green Images
1333 Taylor Creek Road
Christmas, FL 32709
(407) 568-1333
Fax: (407) 568-2061
E-mail: greenimage@aol.com

The Liner Farm
P.O. Box 701369
Saint Cloud, FL 33770-1369
(407) 892-1484
Fax: (407) 892-3593

Plants for Tomorrow
16361 Norris Road
Loxahatchee, FL 33470-9430

Salter Tree Farm
Route 2, Box 1332
Madison, FL 32340
(850) 973-6312

Save-on-Plants Liner Nursery, Inc.
Route 1, Box 500
Arcadia, FL 33821

Superior Trees, Inc.
P.O. Box 9325
U.S. 90 East
Lee, FL 32059
(850) 971-5159
Fax: (850) 971-5416

The Natives
2929 JB Carter Road
Davenport, FL 33837
(813) 422-6664

The Palmetto Patch
1715 Pasco Road
Wesley Chapel, FL 33544
(813) 973-1425

The Wetlands Company, Inc.
P.O. Box 2434
Sarasota, FL 34230

Urban Forestry Services
Route 2, Box 940
Micanopy, FL 32667

Georgia

Oak Pond Farm
Route 1, Box 44
Twin City, GA 30471
(912) 562-3946

Spandle Nursery
Route 2, Box 125
Claxton, GA 30417
(800) 553-5771
Fax: (912) 739-2701
E-mail: spandlag@net.net

Iowa

Cascade Foresty Service
22033 Sillmore Rd
Cascade, IA 52033
(319) 852-3042
Fax: (319) 852-5004
Web page: www.cascadeforestry.com
E-mail: Cascade@netins.net

Louisiana

Bosch Nursery, Inc.
18874 Hwy 4
Jonesboro, LA 71251
(318) 259-9484
Fax: (318) 259-9443

Cypress Creek Nursery
10506 Clay-Ansley Highway
Ruston, LA 71270

Natives Nursery
320 North Theard St.
Covington, LA 70433
(504) 892-5424
Fax: (504) 892-8698
E-mail: natives@wild.net

Northeast Delta RC&D
4274 Front Street
Winnsboro, LA 71295
(318) 435-7328
Fax: (318) 435-7436
E-mail: nedrcd@linknet.net

Richard's Nursery
Route 1, Box 41
Forest Hill, LA 71430

Maryland

Environmental Concern, Inc.
210 West Chew Avenue
P.O. Box P
St. Michaels, MD 21663
(410) 745-9620
Fax: (410) 745-9620

Mississippi

Bear Creek Nursery
1267 Patrick Road
Canton, MS 39046
(601) 898-8071
Fax: (601) 605-1001
E-mail: gh2571@aol.com

Delta View Nursery
Route 1, Box 28
Old Highway 61 South
Leland, MS 38756
(800) 748-9018
Fax: (601) 686-2353
Web page:www.tecinfo.com/~hardwoods
E-mail: hardwoods@tecinfo.com

East of Eden Nursery
Route 2, Box 206A
Yazoo City, MS 39194
(601) 746-5577

Thomas Nursery
Route 2, Box 180A
Highway 11
Enterprise, MS 39330

Yazoo Hardwood Nursery
Rt. 1, Box 76
Philipp, MS 38950
(601) 658-2255
Fax: same as phone number
E-mail: yhnursery@microsped.com

Missouri

Forrest Keeling Nursery
Hwy 79 South
Elsberry, MO 63343
(573) 898-5571

Tom Lett Nursery
Route 2, Box 383C
Cape Girardeau, MO 63701
(573) 335-0909

North Carolina

Weyerhauser
George Hunt Walker Nursery
1123 Dinah's Langing Rd.
Washington, NC 27889
(800) 344-0399
Fax: (252) 946-2218

Oklahoma

Greenleaf Nursery
Route 1, Box 163
Park Hill, OK 74451
(918) 457-5172

Tennessee

Boyd Nursery
P.O. Box 71
McMinnville, TN 37110
(931) 668-4747 or (931) 668-9898
Fax: (931) 668-7646

Greenwood Nursery
636 Myers Cove Rd.
McMinnville, TN 37110
(931) 668-3041 in state or
(800) 426-0958
Fax: (931) 668-2223

Hillis Nursery
92 Gardner Rd.
Highway 56 S
McMinnville, TN 37110
(931) 668-4364
Fax: (931) 668-7432
Web page : www.hillisnursurer.com
E-mail: hillisnsy@blomand.net

Joyner's Hills Nursery
440 Joyner's Hill Road
Bells, TN 38006
(901) 772-4213
Fax: (901) 772-7795

Trees by Touliatos
2020 Brooks Road
Memphis, TN 38116
(901) 346-8065
Fax: (901) 398-5217

Warren County Nursery
6492 Beersheba Hwy
McMinnville, TN 37110
(931) 668-8941
Fax: (931) 668-2245
Web page: wcnursery@blomand.net

Texas

Greenleaf Nursery
HC 62 Box 73
Highway 71 S
El Campa, TX 77437
(409) 543-6891
Fax: (409) 543-1886

Virginia

Union Camp Nursery
18229 Eppes Drive
Capron, VA 23829-0129
(804) 658-4184

Additional Sources of Information

Association of Florida Native Nurseries, 1992, 1992-1993 Plant and Service Locator, P.O. Box 1045, San Antonio, FL 33576, (813) 978-8006.

Plant Industry Division, 1991, Certified Nurseries and Plant Collectors of North Carolina: Raleigh, N.C., North Carolina Department of Agriculture. [Note: Other states may have similar directories.]

Soil Conservation Service Staff, 1992, Directory of Wetland Plant Vendors, Wetlands Research Program Technical Report WRP-SM-1: Vicksburg, Miss., U.S. Army Corps of Engineers, Waterways Experiment Station.

Appendix D
Species-Site Relationships in the Midsouth

Walter Broadfoot (1964) identified a number of soil types in the midsouth that support good growth of bottomland hardwood species. These soil types are located in five soil areas: Mississippi River floodplain (commonly called the Delta), Loess, Coastal Plain, floodplains of the Red and Arkansas Rivers, and the Blackland areas (figs. D.1-D.5).

The following information and tables on soil types is taken almost verbatim from Broadfoot's publication, "Soil Suitability for Hardwoods in the Midsouth." According to Broadfoot, "Information was compiled from data and observation of natural stands and may not apply where physical, chemical, and morphological conditions of the soil have been worsened, or where there are unusual soil variations such as sand ridges and exceptionally dry phases. Species-site relationships in plantations may also differ from those indicated" (Broadfoot, 1964, p. 1-3).

The reader should keep in mind that the footnotes on each table refer to "weed species" and suggest which species to favor or not in management from a timber production point of view. If the forest to be restored will be used for purposes other than timber production, the table symbols and footnotes must be interpreted carefully. Many species that are considered "weeds" from a timber production perspective are often considered desirable for wildlife (see table 4.1).

Delta

The Delta area soils lie in the floodplains of the Mississippi River. The soils are formed from alluvial material washed down from northern parts of the watershed. They are fertile, and under proper management, they are some of the best producers of hardwood timber. Four major types of soils occur in the Delta—recent natural levee, old natural levee, slackwater, and depressional soils—each of which is more suitable for some species than others (table D.1).

Variations in soils of natural levees can be traced to differences in drainage and texture. The alluvial sediments are in the first stages of development because they have been in place such a short time. The soils are usually neutral to alkaline because of lack of leaching. They are light in color because organic matter has not had time to build up.

The old natural levee soils are acid because they have been leached. These soils, in addition to species common on the younger natural levees, support oaks and hickories, as well as sassafras.

The slack-water areas are nearly level or gently sloping, occupy broad areas, and are usually some distance from the present and former channels of the Mississippi River. Their clay content is high and has developed under conditions of poor drainage. These sites support a high species diversity.

Depressional soils occur in old, partly filled river channels throughout the Mississippi River floodplain. These channels provide means for the slow return of flood waters to the bayous and main river. They are the lowest lying soils of the region and are subject to periodic flooding by local runoff. Hardwood species on these soils are limited to those most tolerant of poor drainage and aeration.

Loess

This is the narrow band of wind-deposited soils lying immediately east and west of the Delta. These are mostly upland soils, but support many of the same species found on higher bottomland sites. Soil texture is uniform, usually silt loam to silty clay loam. These soils are highly erodible; if enough erosion has occurred so that a site has less than six inches of topsoil, the site is considered more suitable for pines than hardwoods. Some soils have pans or are underlaid with stiff clays. Pine should also be favored on these sites along with species such as cherrybark, Shumard and white oak and sweetgum. The general soil classes in the Loess area are upland, terraces, acid bottoms, and neutral to alkaline bottoms (table D.2).

Terrace soils in the Loess area show considerable profile development. A number of the terrace soils are poorly drained and have strong pans that seriously limit root development and height growth of hardwoods. Presence of pans should be investigated by use of the soil survey or field inspection.

A number of river floodplains in the Loess area border the Delta on the east. Generally, the same variety of species found on the terraces of this soil are on the bottoms. The middle and lower slopes of the upland and the acid bottoms are particularly productive.

Table D.1. Soil suitability for southern hardwoods in the Delta area. Tree nomenclature follows Little (1953).

Important commercial species	Natural-levee soils					Slackwater soils		Depressional soils	
	Recent		Old						
	Crevasse, Robinsonville	Commerce, Mhoon	Beulah, Bosket	Dubbs, Dundee	Forest-dale	Bowdre, Tunica	Sharkey, Alligator	Ark	Dowling, Souva
Ash, green	●	■	---	○	□	○	■	■	■
Baldcypress	---	●	---	---	○	---	■	●	■
Cottonwood, eastern	■	■	●	●	●	■	■	●	○
Elms, slippery and American	□	□	○	□	□	□	□	○	---
Hackberry and sugarberry	■	■	○	○	□	□	□	□	○
Hickory, water	---	---	---	○	□	○	□	○	□
Honeylocust	○	○	---	○	□	○	□	○	●
Maple, red	---	---	---	○	□	■	■	●	---
Maple, silver	●	■	---	---	---	---	---	---	---
Oak, cherrybark	○	○	■	■	■	●	●	●	---
Oak, Nuttall	---	○	---	●	■	●	■	●	●
Oak, overcup	---	○	---	○	■	○	■	○	■
Oak, Shumard	---	---	●	■	○	●	○	---	---
Oak, swamp chestnut	---	---	○	■	■	●	○	○	---
Oak, water	○	●	■	■	■	■	■	●	---
Oak, willow	---	---	■	■	■	■	■	●	○
Pecan	■	■	○	●	○	●	○	---	---
Persimmon, common	○	○	○	○	□	●	■	●	●
Sassafras	○	---	■	■	○	○	○	---	---
Sweetgum	●	■	■	■	■	■	■	●	○
Sycamore, American	■	■	■	■	●	●	●	○	---
Tupelo, black (black gum)	---	---	□	■	○	○	○	---	---
Tupelo, water	---	---	---	---	---	---	---	●	●
Willow, black	○	■	---	---	○	---	○	■	■

Post and specialty species: black locust, catalpa, and flowering dogwood on moderately to well-drained acid soils; Osage-orange on neutral to alkaline soils; mulberry on all soils.

Limited commercially or in occurrence: boxelder on neutral to alkaline soils; bur oak, American holly, winged elm on acid soils; post oak, river birch, hickories (exc. water), and white oak on well-
, cedar elm, buckeye, and Kentucky coffeetree on all soils.

Weed species: American hornbeam and

■ Occurs frequently; favor in management.
● Occurs occasionally; favor.
□ Occurs frequently; manage, but do not favor.
○ Occurs occasionally; manage, but do not favor.

Table D.2. Soil suitability for southern hardwoods in the Loess area. Tree nomenclature follows Little (1953).

Important commercial species	Uplands						Terraces		Acid bottoms		Neutral to alkaline bottoms	
	Memphis-Loring, Natchez		Lexington, Atwood, Brandon		Grenada, Providence, Franklinton, Dulac, Lax, Tippah	Calloway, Henry, Falkner, Bude, Tickfaw, Hurricane	Lintonia, Richland, Dexter, Freeland	Olivier, Calhoun, Carroll, Hatchie, Almo	Vicksburg, Collins	Falaya, Waverly	Morganfield, Adler	Wakeland, Birds, Dekoven
	Ridge and upper slope	Middle and lower slope[1]	Ridge, upper, and middle slope	Lower slope								
Ash, green and white	○	■	---	○	○	□	○	□	□	■	○	■
Baldcypress	---	---	---	---	---	---	---	---	○	■	○	■
Basswood, American	○	■	---	○	●	○	●	○	●	---	---	---
Beech, American	○	□	---	□	○	○	□	○	□	□	---	---
Cherry, black	○	■	○	●	○	○	●	○	●	○	---	---
Cottonwood, eastern	---	●	---	○	---	---	○	○	■	■	■	■
Elms, slippery and American	○	□	○	□	□	○	□	□	□	□	□	□
Hackberry and sugarberry	---	○	---	○	○	○	○	○	●	●	■	■
Hickories (exc. water)	□	□	□	□	□	○	□	○	□	○	---	---
Honeylocust	---	○	---	○	---	○	---	○	○	□	○	□
Magnolia, southern	○	■	○	○	○	○	●	○	●	●	---	---
Maple, red	○	□	○	□	□	□	□	□	□	■	○	○
Oak, cherrybark	□	■	●	■	■	■	■	●	■	■	○	○
Oak, Nuttall	---	---	---	---	---	---	●	●	●	■	○	○
Oak, overcup	---	---	---	---	---	---	---	○	○	■	---	○
Oak, Shumard	■	■	■	■	■	●	■	●	■	●	○	○
Oak, southern red	□	■	□	■	□	○	●	○	●	○	---	---
Oak, swamp chestnut	○	●	---	○	●	○	●	●	●	■	○	○
Oak, water	□	■	□	■	●	■	●	■	■	■	○	○
Oak, white	■	■	■	■	■	■	●	●	●	●	---	---
Oak, willow	○	●	○	●	○	○	○	○	●	■	---	---
Persimmon, common	□	●	□	○	□	○	□	○	●	■	■	■
Pines	●	○	■	○	○	●	○	●	○	○	---	---
Sassafras	□	●	○	○	○	○	●	○	●	○	○	○
Sweetgum	□	■	□	■	■	■	■	■	■	■	■	■
Sycamore, American	○	●	---	●	●	○	●	○	■	■	●	●
Tupelo, black (black gum)	□	■	□	■	□	□	●	○	●	○	---	---
Yellow-poplar	□	■	□	■	□	○	■	○	■	●	---	---

[1] Includes all slopes greater than 17%.

Post and specialty species: black locust, flowering dogwood, and catalpa on well-drained acid soils; eastern redcedar and mulberry on all soils.

Lim
ac
willow on all poorly drained soils; pecan, chinaberry, cedar elm, winged elm, and buckeye on all soils; spruce pine on acid lower slopes, terraces and bottoms.

Weed species: Eastern hophornbeam, and American hornbeam on acid terraces and bottoms; blackjack oak and smooth sumac

■ Occurs frequently; favor in management
● Occurs occasionally; favor
□ Occurs frequently; manage, but do not favor
○ Occurs occasionally; manage, but do not favor

Coastal Plain

Many soils supporting hardwoods in the midsouth are on terraces and bottoms within the Coastal Plain. In general, they are sandy, acid, and lacking in natural fertility, but some have adequate moisture and drainage for good bottomland hardwood development. Table D.3 lists the major Coastal Plain soils and some of the major hardwood species that naturally occur on them.

Blackland

The Blackland soils occur in Alabama, Mississippi, and eastern Texas, with smaller areas in Louisiana and Arkansas. They are found within the Coastal Plain area, but differ in their prairie-like nature and color. The principal soil classes are shown in table D.4.

Most soils are neutral to alkaline, but some have weathered enough to become slightly acid. Texture is

Table D.3. Soil suitability for southern hardwoods in the Coastal Plain area. Tree nomenclature follows Little (1953).

Important commercial species	Terraces			Bottoms from Coastal Plain materials					
	Cahaba, Kalmia, Amite	Flint, Prentiss, Tilden, Izagora	Stough, Wahee, Myatt, Leaf	Ochlockonee, Iuka, Bruno	Mantachie, Urbo	Bibb	Chastain		Johnston
							Coarse surface	Fine surface	
Ash, green and white	---	○	○	○	□	■	○	●	●
Baldcypress	---	---	---	---	○	■	○	●	●
Beech, American	---	---	---	○	□	○	○	○	---
Birch, river	---	---	---	□	○	---	---	---	---
Cherry, black	●	○	○	■	○	---	---	---	---
Cottonwood, eastern	---	---	○	●	●	●	●	●	---
Elms, slippery and American	○	○	○	□	□	□	○	---	---
Hackberry and sugarberry	---	○	○	●	●	○	○	○	---
Hickories (exc. water)	□	□	○	□	□	○	○	○	---
Magnolia, southern	○	○	---	■	■	○	○	---	---
Maple, red	○	○	□	■	■	■	■	●	□
Oak, cherrybark	●	■	■	■	■	■	■	■	---
Oak, laurel	---	---	○	○	●	■	■	■	---
Oak, Nuttall	---	---	---	---	●	■	●	■	---
Oak, overcup	---	---	---	---	○	□	○	□	---
Oak, Shumard	●	●	●	●	●	●	●	○	---
Oak, southern red	■	■	○	●	●	○	---	---	---
Oak, swamp chestnut	---	●	○	●	■	■	●	○	---
Oak, water	□	■	□	■	■	■	□	□	---
Oak, white	■	■	□	■	■	●	●	○	---
Oak, willow	○	○	□	●	■	●	●	□	---
Persimmon, common	○	○	○	○	●	●	●	●	---
Pines (exc. spruce)	□	□	■	○	○	○	○	○	---
Pine, spruce	---	---	---	●	●	●	●	○	---
Sweetgum	■	■	■	■	■	■	■	■	○
Sycamore, American	---	---	---	■	■	●	●	●	---
Tupelo, black	■	■	□	■	■	□	□	□	---
Tupelo, water	---	---	---	---	---	●	●	●	■
Walnut, black	●	○	○	●	●	○	○	---	---
Yellow-poplar	■	■	□	■	■	■	●	---	●

Post and specialty species: black locust and flowering dogwood on moist, well-drained soils; mulberry on all soils.

Limited commercially or in occurrence: basswood, pecan, post oak, and silver maple on well-drained soils; shingle oak, sweetbay, and swamp tupelo on poorly drained soils; boxelder, winged elm, honeylocust, black willow, sassafras, American holly, buckeye, chinaberry, and common sweetleaf on all soils.

Weed species: blackjack oak and smooth sumac on well-dran
hornbeam, devils-walking-stick, hawthorn, and flatwoods plum on all soils.

■ Occurs frequently; favor in management	□ Occurs frequently; manage, but do not favor
● Occurs occasionally; favor	○ Occurs occasionally; manage, but do not favor

Table D.4. Soil suitability for hardwoods in the Blackland area. Tree nomenclature follows Little (1953).

Important commercial species	Terrace soils:[1] Kipling, Geiger	Bottom soils					
		Recent coarse and medium-textured: Marietta, Verona	Fine-textured acid			Fine-textured calcareous	
			Kaufman	Houlka	Una	Catalpa, West Point	Leeper, Tuscumbia
Ash, green and white	□	■	○	■	■	■	■
Cottonwood, eastern	●	■	●	●	○	■	■
Elms, slippery and American	○	□	○	□	○	□	□
Hackberry and sugarberry	○	■	●	■	□	■	■
Hickories (exc. water)	○	○	□	□	○	---	---
Maple, red	○	□	○	■	□	---	○
Maple, silver	○	○	---	---	---	○	○
Oak, cherrybark	●	●	■	■	■	---	---
Oak, Durand	●	●	■	■	---	●	●
Oak, Nuttall	---	---	●	■	■	○	○
Oak, overcup	---	---	○	○	□	---	○
Oak, post	□	---	---	---	---	---	---
Oak, Shumard	●	●	■	■	○	---	---
Oak, swamp chestnut	○	●	●	■	○	○	---
Oak, water	□	■	●	■	□	○	○
Oak, white	●	---	●	●	●	---	---
Oak, willow	○	■	●	■	□	○	---
Persimmon, common	○	○	○	□	○	---	---
Sweetgum	●	●	■	■	■	●	●
Sycamore, American	○	●	●	●	●	●	●
Tupelo, black	○	○	●	●	○	○	○
Yellow-poplar	---	●	●	●	○	---	---

[1] Noneroded phases only.

Post and specialty species: black locust and catalpa on all wel

Species limited commercially or in occurrence: boxelder, winged elm, honeylocust, and pecan on all soils; American beech, southern magnolia, spruce pine, American holly, shingle oak, sassafras, and chinaberry on all acid soils; black walnut and black cherry on a
poorly drained soils.

Weed species: hawthorn and privet on all soils; American hornbeam, eastern hophornbeam, roughleaf dogwood, and flatwoods plum on all acid soils; smooth sumac on all moist, well-drained soils; redbud and Hercules-club on terraces and acid soils.

■ Occurs frequently; favor in management
● Occurs occasionally; favor
□ Occurs frequently; manage, but do not favor
○ Occurs occasionally; manage, but do not favor

mostly fine or clay-sized. The alluvial soils are fertile enough to support excellent growth of some hardwoods provided moisture and drainage are adequate.

Red and Arkansas River Floodplains

Reddish-brown soils occupy the floodplains of the Arkansas and Red Rivers, and include acid to alkaline sands, silts, and clays. The more alkaline soils occur in the Red River floodplain and the more acid soils occur in the Arkansas River floodplain. The two main soil classes described for this area are terrace and bottom soils (table D.5).

Terrace soils range from moderately to well drained acid soils to somewhat poorly drained to poorly drained acid soils. Bottomland soils range from acid to neutral to alkaline to calcareous in pH. They are generally moderately to well drained.

Table D.5. Soil suitability for hardwoods in the Red area. Tree nomenclature follows Little (1953).

Important commercial species	Terraces			Bottoms			
	McKamie, Hortman, Muskogee	Morse, Asa	Gore, Acadia, Wrightsville	Pulaski, Gallion, Lonoke, Mer Rouge	Yahola, Norwood	Hebert, Portland, Perry	Miller, Buxin, Roebuck, Pledger
Ash, green and white	□	○	□	□	■	■	■
Cottonwood, eastern	---	---	---	●	■	●	●
Elms, slippery and American	□	□	○	□	□	□	□
Hackberry and sugarberry	□	□	○	□	■	□	□
Hickories (exc. water)	□	---	□	□	---	○	○
Honeylocust	---	□	---	○	○	○	□
Oak, cherrybark	■	○	●	■	---	■	---
Oak, Nuttall	●	○	●	●	○	■	○
Oak, overcup	---	---	○	○	○	□	○
Oak, swamp chestnut	□	---	○	■	---	■	○
Oak, water	■	○	●	■	○	■	○
Oak, white	■	---	●	●	---	○	---
Oak, willow	□	○	●	●	---	■	○
Pecan	○	■	---	■	■	○	■
Pines	□	---	□	---	---	---	---
Sweetgum	■	■	■	■	■	■	●
Sycamore, American	●	●	---	■	■	●	●
Tupelo, black	○	---	□	○	---	---	---

Post and specialty species: baldcypress on all poorly drained soils; all soils.

Species limited commercially , winged elm, sassafras, and Shumard oak on , pumpkin ash, water hickory, and pin oak on all poorly drained soils; cedar elm, chinaberry, and red maple on all soils.

Weed species: American hornbeam and eastern o

■ Occurs frequently; favor in management	□ Occurs frequently; manage, but do not favor
● Occurs occasionally; favor	○ Occurs occasionally; manage, but do not favor

References Cited

Broadfoot, W.M., 1964, Soil suitability for hardwoods in the Midsouth: U.S. Forest Service Research Note SO-10, 10 p.

Little, E.L., Jr., 1953, Check list of native and naturalist trees of the United States (including Alaska): U.S. Department of Agriculture Handbook 41, 472 pp.

Appendix E
Species-Site Relationships in the Southern Atlantic Coastal Plain

Recognizing the increasing demand for hardwoods for both pulpwood and sawtimber, the American Pulpwood Association developed a booklet on stands of bottomland hardwoods (Kellison and others, 1988). In this booklet the authors discuss site types, stand assessments, and silvicultural systems and regeneration methods. Kellison and others (1988) discussion on site types is reproduced here with permission.

Recognition of site type is essential for proper management of bottomland hardwoods. Site types are land formations with unique soil and water characteristics and species compositions. Bottomland site types best suited for hardwoods include muck swamps, red river bottoms, black river bottoms, branch bottoms, cypress strands, cypress domes, and Piedmont bottomlands. Hydrologic characteristics and species composition of the bottomland types are shown in table E.1.

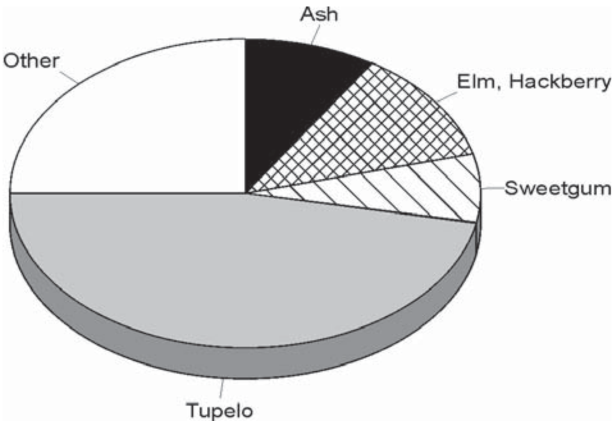
Reference Cited

Kellison, R.C., Martin, J.P., Hansen, G.D., and Lea, R., 1988, Regenerating and managing natural stands of bottomland hardwoods: Washington, D.C., American Pulpwood Association, APA 88-A-6, 26 p.

Table E.1. Bottomland hardwood site types by surface water classification and indicator species.

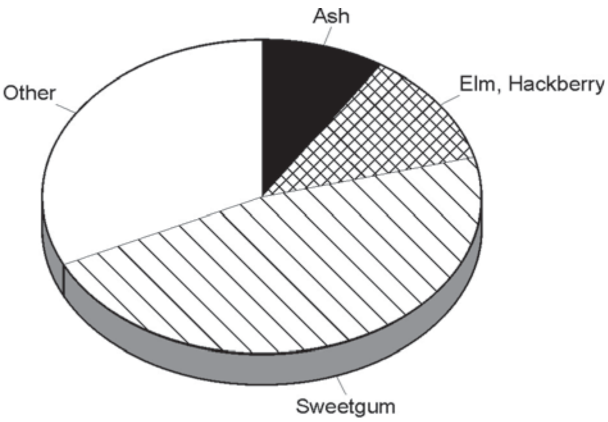
Hardwood Site Type	Surface Water Classification	Indicator Species
Muck swamp	Flooded 10 to 12 months	Baldcypress, tupelo
Red river bottom	Flooded winter, spring	Sycamore, sweetgum, cherrybark oak
Black river bottom	Flooded winter, spring	Tupelo, swamp black gum
Branch bottom	Boggy throughout year	Swamp black gum
Cypress strand	Flooded winter, spring, summer	Baldcypress
Cypress dome	Flooded throughout year	Pondcypress, baldcypress
Piedmont bottomland	Flooded winter	Yellow-poplar, sweetgum

MUCK SWAMP



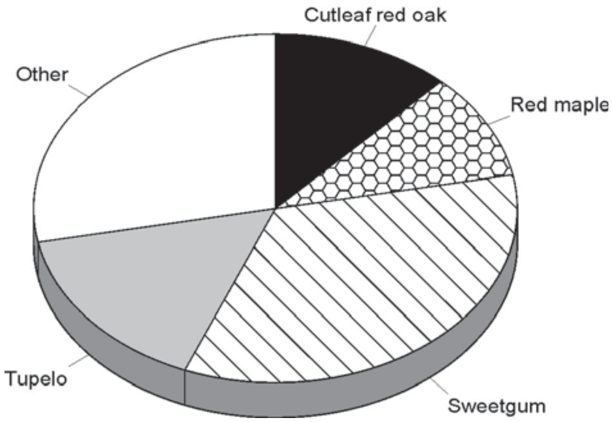
Very poorly drained area, usually with standing water, broad expanses between tidewater and upstream runs and along black rivers and branch bottom stands; also found in miniature in sloughs and old oxbows of red rivers and branch bottoms characterized by accumulation of organic matter (amorphous, lacking structure). Soils range from silt loam through clay. Water tupelo and baldcypress are common in deeply flooded areas and swamp blackgum predominates toward the fringes.

RED RIVER BOTTOM



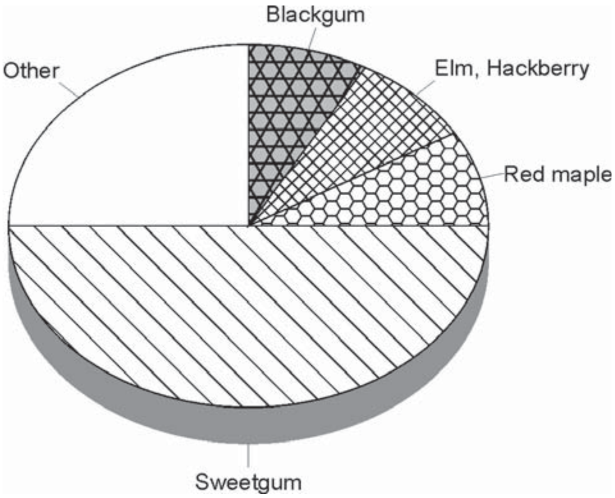
Floodplain of major drainage system originating in the Piedmont or Mountains. Immediately adjacent to the drainage systems, sloughs and oxbows are commonly found; if of sufficient size, they are classified as muck swamps. Some organic matter may accumulate on the clay soils. Water tupelo predominates over cypress, red maple, swamp blackgum, swamp cottonwood, laurel oak and others. Beyond the sloughs and oxbows are first bottoms (low ridges) which flood periodically to considerable depths. However, drainage is fairly rapid because of higher elevation. Soils range from sandy loams or clay loams. Species include sweetgum, ash, water hickory, sycamore, red maple, river birch, elm, hackberry, and willow, water, laurel and overcup oaks. At still higher elevations second bottoms and terraces are found. Flooding is infrequent or rare, and more mesophytic species of cherrybark, swamp chestnut and white oaks, hickories, beech and occasionally yellow-poplar occur. Examples of red river bottom are: Roanoke-Virginia, North Carolina; Santee-South Carolina; Oconee-Georgia; and Alabama-Alabama.

BLACK RIVER BOTTOM



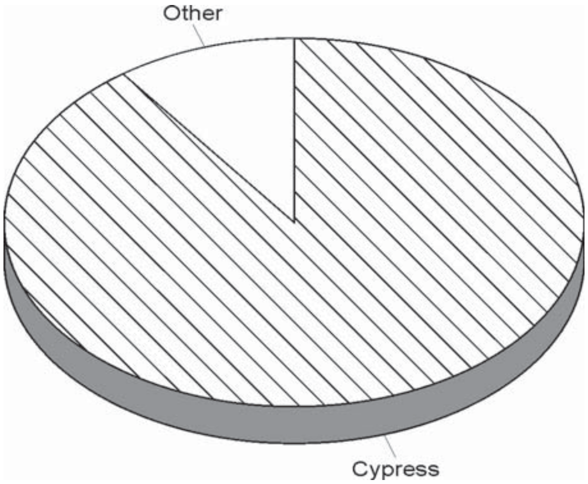
Floodplain of major water system originating in the Coastal Plain. Classification of minor site types and species similar to red river bottom, with exception of muck swamps being more prevalent and first and second bottoms and terraces being on a more modest scale. Predominant species are sweetgum, tupelo, red maple and cut-leaf red oak. Examples of black river bottoms are Blackwater-Virginia; Waccamaw-North Carolina, South Carolina; Black-South Carolina; and St. Mary's-Georgia and Florida.

BRANCH BOTTOM

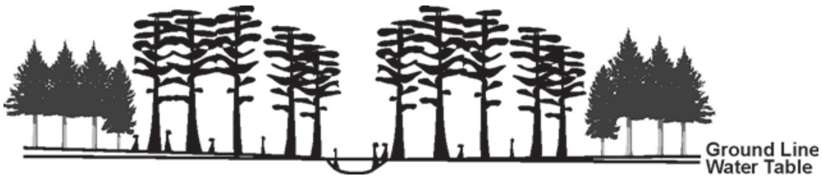


Relatively flat, alluvial land along minor drainage system which is subject to minor overflow. On wetter portions with heavier soils, the predominant species are willow, water and laurel oaks, swamp black gum, sweetgum, red maple and ash. The lighter soils of second bottoms and terraces support cherrybark, Shumard, swamp chestnut, and white oaks, sweetgum, hickory, yellow-poplar and loblolly pine. Sloughs and oxbows of limited extent along the main channel support tupelo and swamp blackgum. Examples: Big Swamp-North Carolina; Wambaw-South Carolina.

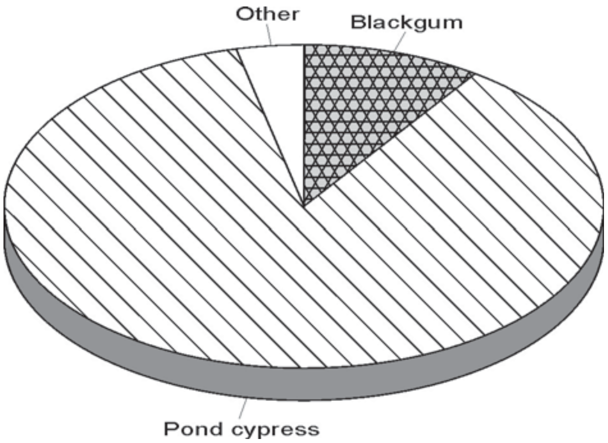
CYPRESS STRAND



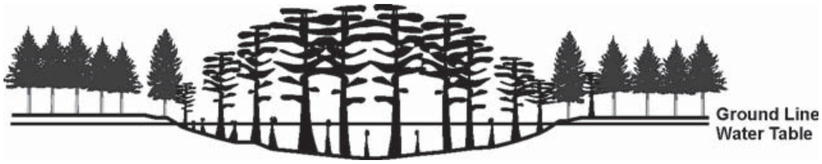
Low areas in south Georgia and northern Florida where shallow water flows during the wet season above the hardpan which is usually present. Such strands or stringers are common in the lower Apalachicola River region, including Tates Hell Swamp. Cypress forests in these strands are usually open with sedges beneath. Some cypress trees extend into adjacent savannahs and boggy flatwoods of slash pine and even longleaf pine. Blackgum is a common associate just beneath the cypress canopy. The soils vary in depth of the surface organic horizon and in the presence or absence of a spodic or an argillic horizon. The values for pH and available nutrients are generally low.



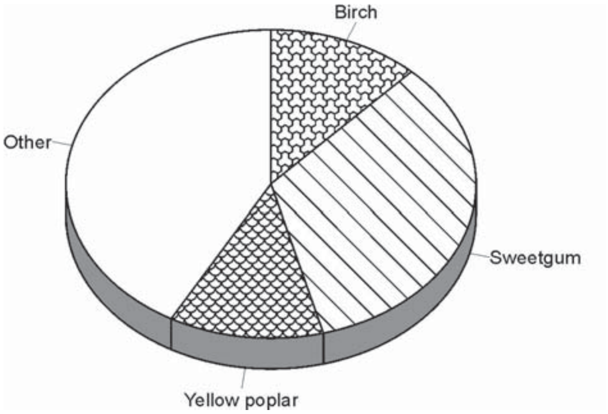
CYPRESS DOME



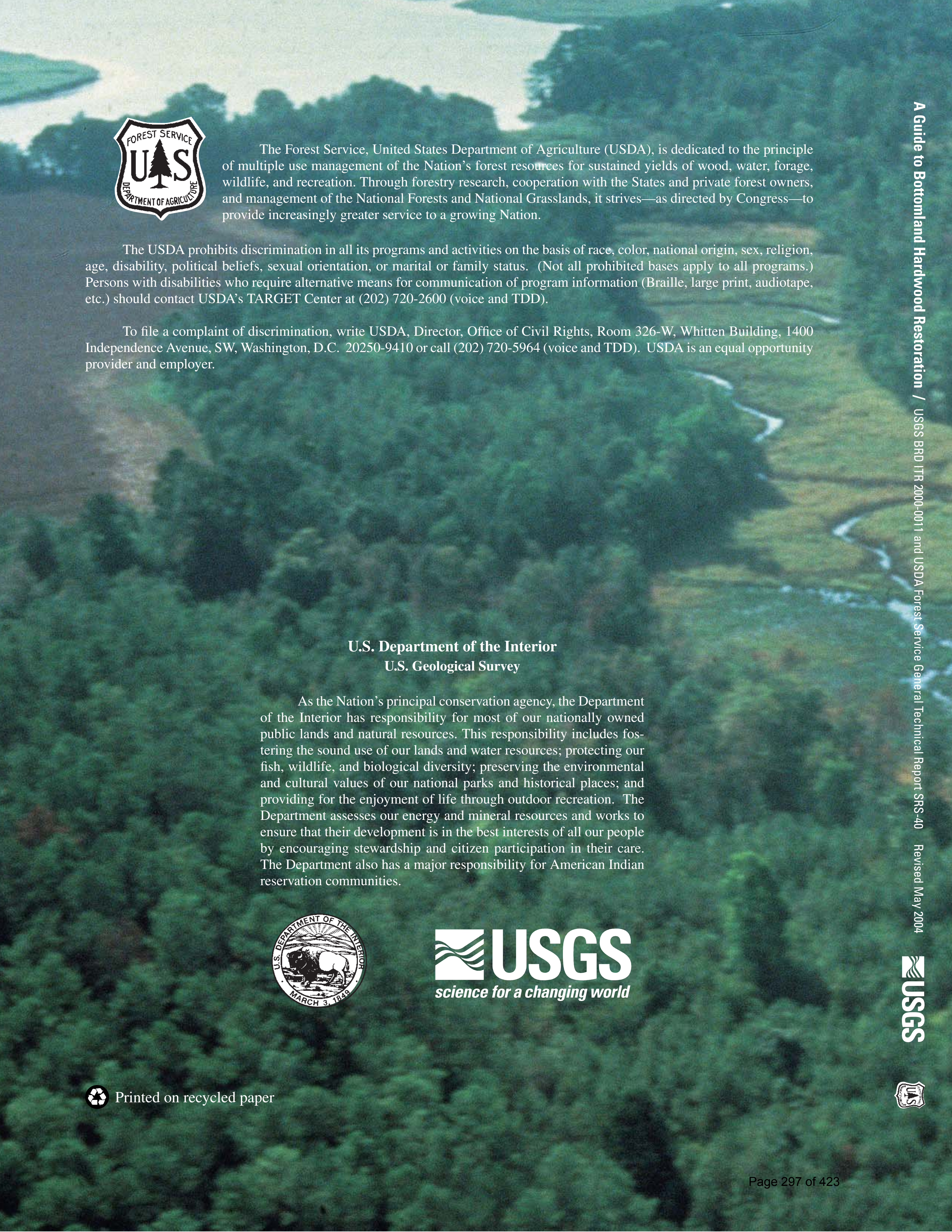
Isolated peaty acid depression (dome) usually found in Florida, which is moist or inundated for weeks or months at a time. Pondcypress predominates but other species such as blackgum, slash pine, sweetbay, and loblolly bay are found on small hummocks where the hydroperiod is less prolonged. Ground cover is usually absent except on hummocks. The tallest trees occur in the center of the domes where peat can accumulate to 2-4 feet in depth; other trees are progressively shorter to the periphery. Domes typically have clay pans or lenses beneath the sandy surface soils which serve to limit subsurface groundwater recharge.



PIEDMONT BOTTOMLAND



In lower Piedmont, conditions identical to red river bottom are encountered. However, upstream, sloughs, oxbows and first bottoms decrease in frequency and area until only well-drained bottomland (second bottom and terrace) is encountered. Species include sycamore, birch, yellow-poplar, sweetgum, green ash, cottonwood, water and willow oak, loblolly pine and others. Examples of bottomland site-types are: Meherrin-Virginia; Neuse-North Carolina; Saluda-South Carolina; Oconee-Georgia; and Sipsey-Alabama.



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Great Trinity Forest Management Plan

HARDWOOD SILVICULTURE

Recognizing and Overcoming Difficult Site Conditions for Afforestation of Bottomland Hardwoods

(Ecological Restoration 22:3 September 2004 Pg 183)

Recognizing and Overcoming Difficult Site Conditions for Afforestation of Bottomland Hardwoods

by J.A. Stanturf, W.H. Conner, E.S. Gardiner,
C.J. Schweitzer and A.W. Ezell

Restoring bottomland hardwoods requires attention to site conditions, matching tree species to the site, and controlling weeds and herbivores in order to achieve success.

In the last decade, about 370,000 acres (150,000 ha) of economically marginal farmland in the Lower Mississippi Alluvial Valley (LMAV) have been restored to bottomland hardwood forests (Stanturf and others 1998, King and Keeland 1999, Schoenholtz and others 2001). Planting of this considerable acreage is due to several federal programs, such as the Wetlands Reserve Program (WRP), that assist landowners by financing afforestation (Figure 1).

Unfortunately, these operational plantings have not performed as well as smaller plantings or research plots (Stanturf and others 2001a). For example, a recent survey of WRP plantings in west-central Mississippi revealed that more than 90 percent of the sites failed to meet the criteria of 100 woody stems per acre (247 stems per ha) three years after planting or direct seeding. While planting 1-0 bareroot seedlings of oak was more successful than direct-seeding acorns, only 23 percent of the land planted with seedlings met the criteria (C.J. Schweitzer unpublished data). Planting and direct seeding oak (*Quercus* spp.) on public land in the same area has been more successful. Meanwhile, Allen (1990) found 70 percent of the planted bottomland hardwood stands on the national wildlife refuges he evaluated had more than 200 trees per acre (494 stems per ha).

We believe that the recurring problems in operational plantings on private lands are due in part to the failure of planters to recognize adverse site conditions and their failure to use appropriate methods for overcoming site limitations. Our objectives in this paper are to synthesize research and experience into guidelines for recognizing adverse site conditions due to hydroperiod, soil, competing vegetation, and herbivory. We describe techniques for overcoming these conditions and suggest promising research areas.

Recognizing Adverse Hydroperiod Conditions

The former agricultural sites available for afforestation are often very low and wet. Even wetland trees suited for these sites require aerated soil conditions during the growing season and their seedlings cannot tolerate overtopping by floodwaters once they have leafed out.

Two conditions of excess water in a floodplain are adverse to tree seedlings: 1) prolonged periods of saturated soil, including persistent standing or flowing water; and 2) high water levels that cover seedlings during the growing season. Seedling tolerance to "flooding" or "waterlogging" generally refers to the ability to

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Figure 1. Workers carrying bags full of dormant tree saplings, mostly oaks, fan out to plant a former agricultural field in the Lower Mississippi River Alluvial Valley to bottomland hardwood forest. *Photo by Emile Gardiner*

withstand saturated soil conditions, in which oxygen is consumed in respiration and soil voids become filled with carbon dioxide and accumulated metabolic products of anaerobic microbes. Some tree species have developed adaptive traits (McKevlin and others 1998) and can acclimate to waterlogging, but at a cost to the plant. Only a few species can withstand waterlogging for extended periods of time during the growing season (Table 1). Even baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*), species that grow in deepwater swamps, require non-flooded conditions for their seeds to germinate.

Immersion of seedlings after they have leafed out in the spring, by overbank or backwater flooding, can cause mortality of even the so-called flood-tolerant species. During the spring and early summer of 1973, Kennedy and Krinard (1974) observed the effects of a major flood on the Mississippi River on planted and natural stands. One growing season after the flood, natural and plantation stands that were one year or older at the time of the flood, and inundated for two months or less, were not severely affected even though the seedlings were less than 2 feet tall. These stands included sweet pecan (*Carya illinoensis*), water oak (*Quercus nigra*), Nuttall oak (*Q. nuttallii*), and cherrybark oak (*Q. falcata* var. *pagodaefolia*). On the other hand, 1-year-old sweetgum (*Liquidambar styraciflua*), which was flooded for three months, was killed. New plantings of cottonwood (*Populus deltoides*) cuttings were destroyed, but the seedlings seemed to do better.

Diagnosing hydroperiod limitations of potential afforestation sites may not be easy, however. Widespread and numerous flood control structures, and the subsequent regulation of river flows, have changed the seasonality and extent of flood events (Dynesius and Nilsson 1994, Ligon and others 1995, Shankman 1999). Position in the landscape (for example, ridge, flat, or slough) and soil characteristics are indicative, but not diagnostic (Baker and Broadfoot 1979) since land leveling and drainage due to farming practices can change site conditions. We recommend obtaining at least a five-year history of flooding on the site before choosing the species to plant. Landowners and farm managers can provide good information about such things as how often in the last five crop years planting was delayed or a crop was lost due to high water.

Overcoming Growing-Season Flooding

Matching species to site is absolutely critical. Species may be planted under less frequently flooded conditions than shown for their tolerance class (Table 2), but not the reverse. For example, baldcypress can be planted and survive on ridges, but cherrybark oak should never be planted in sloughs. If management objectives allow flexibility in the choice of species, simply plant the species adapted to the worst probable flooding conditions. Alternatively, one can plant a mixture of species adapted to a range of flooding regimes and expect significant mortality because some species will fail to meet the site conditions. However, when species composition and stocking are critical (for example, if financial returns from either timber or carbon sequestration payments is an objective), then other strategies, such as controlling flooding, delayed planting and planting in standing water, are available to overcome growing-season flooding.

Controlling Flooding

Controlling flooding during the trees' establishment phase may be possible in some situations. Restorationists may be able to keep sites managed as greentree reservoirs, constructed wetlands, or those downstream from water control structures from flooding while seedlings of moderately tolerant species become established. If flooding is caused by beaver dams, intensive trapping and control may be required for a few years in a small area while seedlings become tall enough to withstand flooding (C. Sloan pers. comm.).

Delayed Planting

Bareroot seedlings should be dormant when planted, which means December to March in the LMAV. Some sites are frequently under water during this optimum planting window, thereby hampering restoration efforts. Avoiding flooded conditions may be possible, although it is often unreliable and expensive. In backwater areas, for example, waiting to plant

Table 1. Waterlogging-tolerance ratings for common tree species endemic to major and minor river bottoms of the southern United States (adapted from Hook 1984).

Most Tolerant

buttonbush (*Cephalanthus occidentalis*)
Carolina ash (*Fraxinus caroliniana*)
pumpkin ash (*Fraxinus profunda*)
swamp-privet (*Forestiera acuminata*)
swamp tupelo (*Nyssa sylvatica* var. *biflora*)
water tupelo (*Nyssa aquatica*)
water-elm (*Planera aquatica*)
black willow (*Salix nigra*)
baldcypress (*Taxodium distichum*)
pondcypress (*Taxodium distichum* var. *nutans*)

Highly Tolerant

water hickory (*Carya aquatica*)
waterlocust (*Gleditsia aquatica*)
overcup oak (*Quercus lyrata*)

Moderately Tolerant

boxelder (*Acer negundo*)
red maple (*Acer rubrum*)
silver maple (*Acer saccharinum*)
river birch (*Betula nigra*)
hawthorn (*Crataegus* spp.)
common persimmon (*Diospyros virginiana*)
green ash (*Fraxinus pennsylvanica*)
honeylocust (*Gleditsia triacanthos*)
deciduous holly (*Ilex decidua*)
sweetgum (*Liquidambar styraciflua*)
sweetbay (*Magnolia virginiana*)
water oak (*Quercus nigra*)
pin oak (*Quercus palustris*)
willow oak (*Quercus phellos*)
Nuttall oak (*Quercus nuttallii*)
sycamore (*Platanus occidentalis*)
eastern cottonwood (*Populus deltoides*)
cedar elm (*Ulmus crassifolia*)

Weakly Tolerant

American hornbeam (*Carpinus caroliniana*)
pecan (*Carya illinoensis*)
shellbark hickory (*Carya laciniosa*)
sugarberry (*Celtis laevigata*)
hackberry (*Celtis occidentalis*)
American holly (*Ilex opaca*)
black walnut (*Juglans nigra*)
red mulberry (*Morus rubra*)
blackgum (*Nyssa sylvatica*)
cherrybark oak (*Quercus falcata* var. *pagodaefolia*)
laurel oak (*Quercus hemisphaerica*)
swamp chestnut oak (*Quercus michauxii*)
Shumard oak (*Quercus shumardii*)
live oak (*Quercus virginiana*)
winged elm (*Ulmus alata*)

Least Tolerant

pawpaw (*Asimina triloba*)
flowering dogwood (*Cornus florida*)
American beech (*Fagus grandifolia*)
yellow-poplar (*Liriodendron tulipifera*)
eastern hophornbeam (*Ostrya virginiana*)
black cherry (*Prunus serotina*)
white oak (*Quercus alba*)
sassafras (*Sassafras albidum*)
slippery elm (*Ulmus rubra*)

Table 2. Waterlogging tolerance classes, in terms of flooding duration and season.

			Tolerance Class		
	Most	Highly	Moderately	Weakly	Least
Duration	100 percent	50-75 percent	50 percent	10 percent[1]	2 percent[1]
Winter	Yes	Yes	Yes	Yes	Yes
Spring	Yes	Yes	Yes	Yes	Seldom
Summer	Yes	1-3 months	Early only	Seldom	No

[1] Refers to growing-season flooding.

until spring floodwaters recede would be desirable, but planting bareroot stock in June is risky (Conner and others 1993, Allen and others 2001). The U.S. Army Corps of Engineers has successfully planted container stock later in the summer (J. Kiser pers. comm.), and other researchers have shown container stock to be effective, but expensive (Williams and Craft 1998, Howell and Harrington 2002, Williams and Stroupe 2002). Cost estimates vary considerably; King and Keeland (1999) surveyed contractors and agencies in the region and determined that planting container seedlings costs \$100 to \$450 per acre, compared with average contractor costs for bareroot seedlings of \$32 to \$250 per acre. Average cost per seedling in 2003-2004 was \$0.20 to \$0.30 for a range of hardwoods, compared with very large container seedlings (5-6 ft tall) costing \$6 each.

Planting in Standing Water

Planting tree seedlings into standing water stresses a seedling more than planting in terrestrial environments. In addition to the normal "shock" of outplanting, nursery grown seedlings planted in water will shed their existing root system and develop one better adapted for life in standing water. Producing a new root system places a large energetic drain on the seedling at a time when it is especially vulnerable to other stresses.

Heavily root pruning tree seedlings is one method of planting in standing water that has been tested extensively in the southern United States. This practice simply involves inserting the seedling into the soil or sediment without digging a hole (Conner 1988, 1993, Conner and Flynn 1989, Reed and McLeod 1994, Hesse and others 1996, Brantley and Conner 1997). The method has been tested in habitats from standing backwater to flowing streams, in coastal and inland areas, and from Louisiana and South Carolina (Figure 2).

Conner and his colleagues (1999) tested bareroot seedlings of baldcypress, water tupelo, and green ash (*Fraxinus pennsylvanica*) pruned to three different severities: moderately, severely, and without roots. In the least severe treatment (moderately pruned), they pruned lateral and taproots to a 9-inch (23-cm) spread. Severely pruned seedlings had all of the lateral roots removed and the taproot pruned to 9 inches (23 cm). Moderately and severely pruned seedlings were planted by grasping the seedling at the root collar and inserting it 8 inches (20 cm) deep into soft sediment. Cuttings without roots were prepared by removing all of the root system below the root collar and dipping the cut end into a commercially available rooting hormone. They were planted like the other stock.

Figure 2. Planting techniques for areas with standing water and soft sediments include planting severely pruned bald cypress (*Taxodium distichium*) seedlings. In this practice, the lateral roots of the bald cypress seedlings are removed and the tap root is cut to 9 inches long. The seedlings are then inserted into the soil or sediment without digging a hole. *Photo by William H. Conner*

The researchers found that survival of baldcypress and water tupelo seedlings was excellent in both the severe and moderately severe pruning treatments. Both these species are well suited to wet environments (Table 1) and pruned seedlings are quickly and easily planted in standing water. Moderately root-pruned seedlings of baldcypress and water tupelo planted in water 1 foot to 2 feet (30-60 cm) deep survived as well as seedlings planted in shallower water. Total removal of the root system was detrimental to both cypress and tupelo, although there was some survival (33 percent) of baldcypress cuttings after three years. No amount of root pruning was appropriate for green ash seedlings after three years of almost continuous flooding.

Recognizing Adverse Soil Conditions

Growth of bottomland hardwoods depends on the physical condition of the soil, moisture availability during the growing season, nutrient availability, and aeration (Baker and Broadfoot 1979). Bottomland oaks, the most frequently planted bottomland hardwood species (King and Keeland 1999, Schoenholtz and others 2001), grow best on moist, well-drained sites with good fertility and medium-textured soils. However, heavy clay soils typify most areas available for afforestation and, on these soils, oak survival is often lower and growth less substantial (Stanturf and others 1998). Seedlings planted in clay soils frequently face moisture stress during late-summer periods of low rainfall.

Traffic pans (compacted layers formed under pressure of repeated passes by equipment on the surface) are a fairly common occurrence in the LMAV, especially in soils with high silt content. They usually form just below the average depth of agricultural cultivation, about 6 to 8 inches (15-20 cm). Traffic pans impede tree root penetration in soil, thereby reducing the seedling's access to the soil's resources.

Soil chemistry is another concern when planting bottomland hardwoods. Most oaks grow best in soils with a pH range from 6.0 to 7.0. Unfortunately, recent alluvial deposits may have a pH approaching 8.0. These soils can be a problem because some oak species, especially Nuttall, cherrybark and water oaks (Kennedy 1993), experience low vigor and increased mortality, largely due to a lack of iron at this pH level.

Each of these soil conditions require the restorationist to take corrective actions that should include 1) matching the species to the site conditions, 2) site preparation, and 3) soil amelioration.

Overcoming Soil Limitations

Matching Species to Site

Hardwood foresters use a publication by Baker and Broadfoot (1979) to match species to site for establishing timber plantations. This approach involves estimating productivity from site characteristics. While there is no rule for correlating productivity measures with afforestation potential for wildlife or other purposes, several researchers, including the lead author of this article, have suggested that a site be at least minimally acceptable for a tree species (Stanturf and others 1998, Groninger and others 2000). According to Baker and Broadfoot (1979), that would mean a site is capable of achieving at least 54 percent to 63 percent of the maximum productivity level for that species.

As mentioned above, several oak species do not survive or grow well on high pH soils. Shumard oak (*Q. shumardii*), however, has been planted successfully on high pH soils where other oaks are unsuitable (Kennedy and Krinard 1985). In three separate plantings, Shumard oak survived and grew well on soils with pH from 7.8 to 8.0. Other hardwoods, such as green ash and sycamore, are more tolerant than oaks of slightly alkaline conditions (Baker and Broadfoot 1979).

Site Preparation

Site preparation prior to planting former agricultural land requires disking at least twice with a heavy disk, in late summer or early fall. Disking should be to a depth of at least 8 inches (20 cm), preferably to 15 inches (38 cm). Deeper plowing or ripping is recommended for sites with traffic pans. In heavy clay soils, ripping should be with a straight shank because winged rippers leave subsurface voids that are accentuated by shrinking in summer, causing root desiccation and seedling mortality. Ripping is commonly prescribed for cottonwood on all soils to ease the planting of cuttings.

Site preparation for cottonwood plantings on former agricultural land is more intensive than that generally practiced for other hardwoods (Stanturf and Portwood 1999, Stanturf and others 2001b). Ideally, site preparation begins immediately following soybean harvest. If soybeans are harvested with a combine, plant residues are chopped and shredded; the fine debris poses no problems. The first step in site preparation is double disking (disking in two passes, each perpendicular to the other). Ripping with a straight shank breaks up the subsoil. If a traffic pan has developed, subsoiling with a winged ripper will break up the pan more completely than will a straight shank. However, subsoiling with a winged ripper must be done a year before planting to allow voids to fill and cracks to close. Liquid nitrogen fertilizer is added in the same pass to the planting slit made by the ripping shank. Specialized equipment places the fertilizer 18 to 20 inches (46-51 cm) deep in the slit. On Sharkey (Aeric Epiaquerts) and other expanding clay soils, it is essential for the slit to undergo several wetting and drying cycles (from precipitation) in order for fine particles to move into and fill the slit. Otherwise, soil drying in the spring and summer will cause the soil to crack along the planting slit, exposing tree roots to desiccation.

Soil Amelioration

In other areas of the South, bottomland soils may not be as fertile as it is in the LMAV (Francis 1985), and available phosphorus may limit seedling growth (Stanturf and Schoenholtz 1998). In the LMAV, agricultural soils have lower organic matter content and may be depleted of nitrogen (Gardiner and others 2001). For this reason, high nitrogen demanding species, such as cottonwood, receive nitrogen fertilizer at time of planting. Although fertilization may not be justified economically in terms of increased wood production, early height growth may reduce risk from flooding and herbivory. Broadcast fertilization at time of planting may stimulate weed competition prompting extensive weed control for several years after planting. Few guidelines are available for fertilizing hardwood plantings other than cottonwood.

Recognizing Competing Vegetation

Even when species have been properly matched to site and soil conditions, they must compete with weeds. Three conditions of competing vegetation can be recognized: 1) the "normal" weed complex on the site—a legacy of past land use and surrounding seed sources; 2) "problem" weeds, particularly woody vines; and 3) "invasive," non-native species. Generally, pressure from herbaceous competition will be severe in old agricultural fields. Many weed species are present there in rootstocks or buried seed that may not be visible immediately after crops are harvested.

"Problem" weeds must be recognized and controlled prior to establishing hardwoods because there are no operational control options once hardwoods are planted. Kudzu (*Pueraria montana*), Japanese honeysuckle (*Lonicera japonica*), pepper-vine (*Ampelopsis arborea*), and trumpet creeper (*Campsis radicans*) are serious problems, as are bahiagrass and dallisgrass (*Paspallum* spp.). Broom sedge (*Andropogon virginicus*) is not as serious as the others listed here, but requires control prior to establishment.

Non-native invasive species on bottomland hardwood sites include Japanese climbing fern (*Lygodium japonicum*), cogongrass (*Imperata cylindrica*), Chinese tallow (*Sapium sebiferum*), Japanese and Chinese privet (*Ligustrum japonicum, L. sinense*), Japanese honeysuckle, and Chinese wisteria (*Wisteria sinensis*). Most of these species can be controlled with herbicides (Table 3), but all these non-native species are difficult or impossible to control after planting, without harming the tree species.

Overcoming Competing Vegetation

There are two basic methods for controlling competing vegetation—cultivation and herbicides.

Cultivation

Common practice in bottomland hardwood afforestation programs has been to plant without any site preparation immediately after the agricultural crop has been harvested, or simply to disk once on fallowed sites (Stanturf and others 1998). Cottonwood is a special case, where double disking and herbicides are used (Stanturf and others 2001b). Kennedy (1981a, 1981b) compared mowing or disking to no competition control and found that mowing was as ineffective as no control. Disking, on the other hand, can significantly improve the survival and growth of bottomland hardwood seedlings (Houston and Bucknor 1989, Kennedy 1981a, 1981b), although access on wet sites can limit use of cultivation as a weed control technique.

Herbicides

In old fields with a "normal" weed complex, herbicides consistently improve the survival of oak by as much as 25 percent and sweetgum from 10 percent to 15 percent. For cottonwood, herbicides can improve survival by 25 percent compared to mechanical control and by as much as 80 percent compared to no control (Stanturf and others 2001b).

In fields with problem species, such as woody vines, it is common to see seedling mortality of 60 percent or more even when herbaceous competition has been controlled. If problem species or non-native invasive plants are present, effective competition control prior to planting will likely determine the success or failure of a restoration effort.

Chemical Site Preparation

Many herbicides labeled for broadcast application can be used for bottomland hardwood site preparation (Anon. 1999)

Table 3. Chemical control options for woody vines and non-native invasive species. Effective control of these problem species requires application prior to planting hardwood seedlings (Source: Miller 1997).

Problem Species	Herbicide	Comment
kudzu (*Pueria montana*)	Tordon® K Escort®	Follow-up applications are often required. Escort® may be the better choice because it has less risk of damaging the planted seedling.
Japanese honeysuckle (*Lonicera japonica*)	Escort® (metsulfuron methyl) Accord® (glyphosate)	Needs higher rate of Accord® than for site preparation.
pepper-vine (*Ampelopsis arborea*)	Vanquish® or Banvel® (dicambra)	Extremely aggressive in abandoned fields; will cause significant mortality. Must be "non-crop area" or pasture, not labeled for forestry use.
trumpet creeper (*Campsis radicans*)	Accord® (glyphosate)	
redvine (*Brunnichea cirrhosa*)		
cogongrass (*Imperata cylindrica*)	Arsenal® (imazapyr) or Arsenal®/Accord® (glyphosate)	High rates of Arsenal® or tank mix Arsenal®/Accord® prior to planting.
Chinese tallow (*Sapium sebiferum*)	Arsenal® (imazapyr) or Accord® (glyphosate) prior to planting	Apply pre-plant, with spot treatments (directed spray) of Accord® after planting.
Japanese privet (*Ligustrum japonicum*)		
Chinese privet (*L. sinense*)	Arsenal® (imazapyr; high rates) or Chopper® (imazapyr) for control	Accord® (glyphosate) at high rates only will suppress privet.
Chinese wisteria (*Wisteria sinensis*)	Garlon® 4 (triclopyr)	Pre-plant application controls from early to mid summer; control decreases later in the growing season and follow-up treatment by directed spray of Garlon® 4 may be required.
Japanese climbing fern (*Lygodium japonicum*)		Cannot be controlled by any available herbicide.

(Table 3). Arsenal AC® (imazapyr), which is labeled for hardwood management, is extremely lethal to a broad spectrum of woody and herbaceous species. It is an effective chemical for site preparation but, because of its soil activity, sufficient time must elapse between application and planting seedlings. Other herbicides containing picloram are labeled for hardwood management (Allen and others 2001) but are seldom used (Tordon® 101 and Tordon® 101R, Tordon® K, Tordon® RTU, Access®, Pathway®). In some limited cases where injection of undesirable hardwoods is required, Chopper® (EC formulation of imazapyr) may be useful. For most purposes, broadcast application is recommended for site preparation rather than spot or banded application because planting spots are better identified under actual planting conditions. Another reason to favor broadcast application is the vigorous regrowth of the main competitors. Clearing small areas around a newly planted seedling likely would be ineffective.

Weed Control After Planting

Controlling groundlayer weeds is possible after tree planting, but care must be taken to use the proper herbicide for the given situation. Oust® (sulfometuron methyl) controls many broadleaves and some grasses but does not harm woody species (Ezell and Catchot 1997, Groninger and Babassana 2002). It can be applied after planting, but before seedlings break dormancy. Atrazine® 4L and Princep® 4L (atrazine and simazine) are other pre-emergent herbicides that are effective on broadleaves.

Goal® 2XL (oxyfluorfen) has shown excellent control of broadleaves in tests, with some grass control but no damage to hardwoods (Ezell 1999a). It is currently labeled for use on cottonwood and hybrid poplar. Scepter® 70DG (imazaquin) provides excellent broadleaf control in tests with no damage to crop species such as oak, sweetgum, or cottonwood. It is currently labeled for cottonwood and the label could be expanded to other hardwoods.

Milestone® (azafenidon) is a pre-emergent herbicide for broadleaf control. It has shown to be very effective in tank mixes with Oust®, with no damage to the crop oaks (Ezell 1999b). Milestone is currently labeled for use in citrus orchards.

Endurance® (prodiamine) provides good herbaceous control in pre-emergent application. It has been tested on cottonwood and could prove to be a good product for hardwoods.

Many herbicides are effective against grasses and all are applied post-emergent. Fusilade® DX (fluazifop-butyl) controls many grasses with the best results obtained by making two applications, each at half the total recommended application rate. Vantage® and Poast® are both sethoxydium with broad-spectrum control of grasses, but no effect on broadleaves. These two herbicides work best when crop oil is used as a surfactant, although this can burn hardwood foliage. Select® (clethodim) is another effective grass herbicide that can be used either with crop oil or a non-ionic surfactant.

Herbicides can be applied as a broadcast spray from a backpack sprayer for small areas or with a mechanized rig using a farm tractor or an all-terrain vehicle. Banded spraying (spraying in between the tree plantings) may be effective if the weed complex is known beforehand and is not very vigorous.

Woody Control After Planting

Ideally, adequate site preparation will preclude the need to control woody species after planting. If some control of woody species is needed after planting, directed spray of foliar-active herbicides is the preferred method. Useful products include Accord® (glyphosate) and Garlon® 3A (triclopyr). Spray drift must be minimized and contact with crop species avoided (Miller 1993).

Recognizing Adverse Effects of Herbivory

Herbivory can dramatically affect the survival and growth of bottomland hardwood seedlings. The major herbivores are beaver (*Castor canadensis*), nutria (*Myocastor coypus*), and, in some localized situations, white-tail deer (*Odocoileus virginianus*). Small mammals, mostly rodents (for example, hispid cotton rat [*Sigmodon hispidus*]) and rabbits (*Sylvilagus* spp.), are often responsible for failures of directly seeded plantings.

Overcoming Herbivory

There are three basic measures that foresters and restorationists in the LMAV use to overcome the effects of herbivorous animals. They are fencing, tree shelters, and reducing the amount of plant cover.

Fencing

Fencing has been used to increase the survival of natural and planted seedlings by excluding large herbivores, such as deer, from regeneration areas. Cattle-wire fence (8-ft-tall) has proven most effective at excluding deer in the northeastern United States (Marquis and Brenneman 1981). Woven wire fence and debris fences have been used in the southern United States to protect commercial cottonwood plantations from deer and hogs (McKnight 1970). In 2001, we fenced an experimental area with 8-ft-high tensile steel deer fence at an installed cost of $3.95 per linear foot, which included the cost of installing 2-ft-tall poultry wire at the base of the deer fence to exclude rabbits. For comparison, a 10-acre (4-ha) site would cost $1,471 or more, depending upon layout. Although electric fencing has proven effective in northern hardwoods (Marquis and Brenneman 1981), flooding makes this impractical in most bottomlands.

Tree Shelters

The benefits of tree shelters—decreased herbivory, stimulated seedling growth, and increased seedling survival—have been documented for northern climates, mostly in cutover natural stands (Frearson and Weiss 1987, Lantagne and others 1990, Ponder 1995, Gillespie and others 1996). On bottomland sites subject to heavy browsing, tree shelters may be the only means of successful afforestation (Conner 1988, 1993, Reed and McLeod 1994). Shelters may increase the competitiveness of slower-growing species, such as oaks (Schweitzer and others 1999), but height gains often are due to temporary shifts in biomass accumulation and are not maintained once seedlings grow above the shelter (Gardiner and others 2002).

> Beaver have been observed grazing on seedlings when floodwater exceeds the height of the shelter. Installing shelters taller than the depth of expected flood levels is the only way to prevent this type of herbivory.

Several types of tree protection devices have been tested over the past two decades. In the mid-1980s, Conner and Toliver (1987) experimented with Vexar® plastic mesh tubes and found that they did not protect baldcypress seedlings from nutria. Plastic tree shelters from 2 ft (60-cm) to 5 ft (150-cm) tall have been tested in various experiments in southern bottomland and wetland sites (Conner 1988, 1993, Reed and McLeod 1994, Schweitzer and others 1999, Conner and others 2000). Double-wall plastic shelters (commercially available as Tubex® or TreePro®) protect seedlings from herbivores and create a microenvironment with increased carbon dioxide, humidity, and temperature (Figure 3).

Tree shelters are not a guarantee against mortality from animal herbivory, however. In most wet areas, 1-ft (30-cm) tall tree shelters are generally sufficient to prevent clipping by rabbits or nutria, but taller shelters are necessary to prevent excessive browsing by deer. Beaver have been observed grazing on seedlings when floodwater exceeds the height of the shelter (Reed and McLeod 1994). Installing shelters taller than the depth of expected

Figure 3. Double-walled tree shelters are used in bottomland hardwood restorations to protect young trees from herbivory by deer, rabbits and nutria, and to create a microenvironment that accelerates tree growth. *Photo by Wayne Inabinette*

flood levels is the only way to prevent this type of herbivory.

The cost-effectiveness of tree shelters for large restoration areas is uncertain. Material cost for tubular shelters is about $1.75 each for 2-ft-tall and $4.17 for 4-ft-tall shelters, plus the costs of installation and removal. Shelters are easily knocked down and swept away by floodwaters. Because of their high cost and uncertain effectiveness, tree shelters probably should be limited to small areas of very severe herbivory, in conjunction with control of weed cover (for small mammals) and herbivore suppression (beaver and nutria).

Reducing Cover

Small mammals are abundant on afforestation sites (Willis and others 1996) and often are suspected of eating or caching direct-seeded acorns. They also will clip seedling tops or girdle stems and clip roots (Savage and others 1996). Oak seedlings can resprout and will usually overcome animal browsing (Lasher and Hill 1977, Schweitzer and others 1997), provided it is not continuous. Baldcypress also resprouts readily, although green ash resprouts less readily, and water tupelo not at all (Conner and others 1999). On most sites, control of herbaceous vegetation removes cover for small mammals and reduces their effect on seedlings. Tree shelters also provide some protection, although some small mammals may tunnel under the bottom of the shelter (P. Madsen pers. comm.).

Summary

Proper diagnosis of site conditions and selection of appropriate species are critical to achieving adequate survival and growth of restored bottomland hardwoods in the LMAV. Guidelines (Baker and Broadfoot 1979, Hook 1984; Tables 1 and 2) are available for matching species to a given site and hydroperiod, according to their tolerance to waterlogging and their growth potential. We think these guidelines should be combined with information on other adverse site conditions, such as competition and herbivory, in order to develop prescriptions that are cost effective.

Gardiner and his associates (2002) provide a comprehensive review of research needs for establishing bottomland hardwoods under all site conditions. We would like to suggest the following research needs, which we believe are specific to establishing bottomland hardwoods under adverse site conditions. These needs include 1) better guidelines for properly fertilizing these former agricultural sites, 2) experiments with taller seedling, and 3) determine better management and control of troublesome weeds.

Fertilizing Agricultural Sites

Seedling vigor can be enhanced by fertilization, but guidelines are needed for nitrogen on former agricultural fields and phosphorous on less fertile sites (Francis 1985, Stanturf and Schoenholtz 1998, Gardiner and others 2002). Continuous cropping depletes soil organic matter and associated nutrients, particularly nitrogen. Nitrogen is routinely added in cottonwood plantings, as liquid fertilizer in the planting slit (Stanturf and others 2001b), to boost early height growth. Most research with other species has shown them to be less responsive to fertilizers, although evaluations have been for long-term effect on biomass production. It also could be cost effective to maximize short-term growth in height by placing a seedling beyond the range of deer or flooding and increase its ability to compete with weeds. Species characteristics and site conditions will determine when to add the correct fertilizer in the optimal amounts. Generally, fertilization accompanied by weed control produces the best results.

Planting Taller Seedlings

Simply planting taller seedlings may overcome many limitations associated with flooding and herbivory. Seedlings taller than floodwaters should withstand even summer flooding, as long as high water temperature does not reduce dissolved oxygen to lethal levels (Kennedy and Krinard 1974). Tall seedlings with upper leaves beyond the reach of deer may reduce some effects of herbivory.

Some work suggests that planting tall stock is feasible. McKnight (1970), for example, described a technique for planting rooted cuttings of cottonwood in areas subject to deep overflows. Whips with a 16-20 ft (5-6 m) long sprout and 2 feet (60 cm) of belowground material were planted in a hole 40 inches (1 m) deep. McKnight reported that the initial growth was poor but survival and subsequent growth were high. Stanturf (1995) and Stanturf and Kennedy (1996) studied the results of planting 2-0 bareroot cherrybark oak seedlings on a cutover site in South Carolina. Two planting depths (1 ft and 2 ft [30 cm and 60 cm]) and top pruning were compared. After 11 years, the researchers found that the cherrybark oaks averaged 23.6 feet (7.2 m) in height. They also noted that there were no significant differences in height or dbh among treatments and survival exceeded 50 percent.

The main disadvantage of taller seedlings is the difficulty of planting them, which leads to higher costs. In other studies (Stanturf 1995, Stanturf and Kennedy 1996), oak seedlings up to 2.5 feet (0.8 m) tall were planted. This process required the use of a gasoline-powered posthole digger that required two people to operate and a separate two-person crew to place the seedling and backfill. If fewer tall seedlings can be planted, and replanting of failed seedlings avoided, the cost differential may not be so great. Tree shelters may stimulate height growth and provide additional physical protection from herbivory.

Better Control of Competing Plants

Bottomland hardwood plantings under WRP seldom benefit from effective control of competing vegetation (Stanturf and others 1998, Stanturf and others 2001a). The standard practice is "disk, plant, and walk away" without controlling woody vine competition. Some agencies and a few landowners are averse to using herbicides, and cost-sharing programs, such as the Conservation Reserve Program, seldom reimburse establishment expenses incurred after the first year. Yet, woody vines and non-native invasive plants are only controlled effectively by herbicide applied prior to planting and often require spot application for two years after planting (Gardiner and others 2002). Herbaceous species, such as giant ragweed (*Ambrosia trifida*), are also fierce competitors for site resources and must be controlled when establishing cottonwood (Stanturf and others 2001b). The economic benefit of competition control for other hardwoods has not been documented, but small trials show promising results in terms of survival and early height growth.

Mechanical weed control is used effectively on some better drained sites, but may be impossible on adverse sites because saturated soil hinders operations at critical times. Fabric mats may provide an alternative to herbicides in these situations. To control weeds effectively, fabric mats must be applied early, remain intact, and be large enough to provide the seedling with protection (Haywood 1999). Limited results show the promise of fabric mats improving survival and growth (Adams 1997, Schweitzer and others 1999). Fabric mats on flooded sites may be ineffective, however, as floodwater may lift and float the mats away. The cost of mats may prohibit use in afforesting large areas. Although the cost of materials is moderate (less than $0.50 each with staples, depending upon material and size of mat), installation costs are high because each mat must be anchored (McDonald and Helgerson 1990, Haywood 1999). Nevertheless, the potential of mulch mats and tree shelters deserve further testing, especially under conditions of interacting stressors, such as herbivory and flooding.

Tree shelters, weed control, and fertilizers may stimulate height growth of normal-sized seedlings sufficiently to overcome effects of growing season flooding. Additional research is needed, particularly side-by-side comparisons, to identify cost-effective combinations of stock type, vegetation control, fertilization, and protective devices.

REFERENCES

Adams, J.C. 1997. Mulching improves early growth of four oak species in plantation establishment. *Southern Journal of Applied Forestry* 21:44-46.

Allen, J.A. 1990. Establishment and growth of bottomland oak plantations on the Yazoo National Wildlife Refuge Complex. *Southern Journal of Applied Forestry* 14:206-210.

Allen, J.A., B.D. Keeland, J.A. Stanturf, A.F. Clewell and H.E. Kennedy, Jr. 2001. A guide to bottomland hardwood restoration: U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD/ITR-2000-0011, U. S. Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-40.

Anon. 1999. 1999 *Crop protection reference*. 15th ed. New York: C&P Press.

Baker, J.B. and W.M. Broadfoot. 1979. Site evaluation for commercially important southern hardwoods. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station, General Technical Report SO-26. New Orleans, Louisiana.

Brantley, E.F. and W.H. Conner. 1997. Growth of root-pruned seedlings in a thermally impacted area in South Carolina. *Tree Planter's Notes* 48(3-4):76-80.

Conner, W.H. 1988. Natural and artificial regeneration of baldcypress (*Taxodium distichum* [L.] Rich.) in the Barataria Basins of Louisiana. Ph.D. dissertation. Baton Rouge, LA: Louisiana State University.

__. 1993. Artificial regeneration of baldcypress in three South Carolina forested wetland areas after Hurricane Hugo. Pages 185-188 in J.C. Brissette (ed.), Proceedings of the seventh biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana. General Technical Report GTR-SO-93.

Conner, W.H. and K. Flynn. 1989. Growth and survival of baldcypress (*Taxodium distichum* [L.] Rich.) planted across a flooding gradient in a Louisiana bottomland forest. *Wetlands* 9:207-217.

Conner, W.H., L.W. Inabinette and E.L. Funderburke. 2000. The use of tree shelters in restoring forest species to floodplain delta: 5-year results. *Ecological Engineering* 15(Suppl. 1):S47-S56.

Conner, W.H., K.W. McLeod, L.W. Inabinette, V.H. Parrish and M.R. Reed. 1999. Successful planting of tree seedlings in wet areas. Pages 201-204 in J.D. Haywood (ed.), Proceedings of the tenth biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-30.

Conner, W.H. and J.R. Toliver. 1987. Vexar seedling protectors did not reduce nutria damage to planted baldcypress seedlings. *Tree Planter's Notes* 38:26-29.

Conner, W.H., J.R. Toliver and G.R. Askew. 1993. Artificial regeneration of baldcypress in a Louisiana crayfish pond. *Southern Journal Applied Forestry* 17:54-57.

D'Antonio, C. and L.A. Meyerson. 2002. Exotic plant species as problems and solutions in ecological restoration: A synthesis. *Restoration Ecology* 10:703-713.

Dynesius, M. and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266:754-762.

Ezell, A.W. 1999a. Crop tolerance of five hardwood species to pre-emergent and post-emergent applications of oxyfluorfen. *Proceedings of the Weed Science Society of America* 39:183.

__. 1999b. Pre-emergent applications of azafenidon for crop tolerance testing in loblolly pine, cherrybark oak, Nuttall oak, and willow oak. *Proceedings of the Weed Science Society of America* 39:182.

Ezell, A.W. and A.L. Catchot, Jr. 1997. Pre-emergent and post-emergent applications of sulfometuron methyl for competition control in oak plantations. *Proceedings of the Southern Weed Science Society* 50:109-111.

Francis, J.K. 1985. Bottomland hardwood fertilization—the Stoneville experience. Pages 346-350 in E. Shoulders (ed.), Proceedings of the third biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Forest and Experiment Station, New Orleans, Louisiana. General Technical Report SO-54.

Frearson, K. and N.D. Weiss. 1987. Improved growth rates within tree shelters. *Quarterly Journal of Forestry* 81:184-187.

Gardiner, E.S., D.R. Russell, M. Oliver, and L.C. Dorris, Jr. 2002. Bottomland hardwood afforestation: state of the art. Pages 75-86 in M. Holland, M.E. Warren, Jr., and J.A. Stanturf, editors, Proceedings of the conference on sustainability of wetlands and water resources. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. General Technical Report SRS-50.

Gardiner, E.S., C.J. Schweitzer and J.A. Stanturf. 2001. Photosynthesis of Nuttall oak (*Quercus nuttallii* Palm.) seedlings interplanted beneath an Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) nurse crop. *Forest Ecology and Management* 149:283-294.

Gillespie, A.R., R. Rathfon and R.K. Meyers. 1996. Rehabilitating a young northern red oak planting under tree shelters. *Northern Journal of Applied Forestry* 13:24-29.

Groninger, J.W., W.M. Aust, M. Miwa and J.A. Stanturf. 2000. Growth predictions for tree species planted on marginal soybean lands in the Lower Mississippi Valley. *Journal of Soil and Water Conservation* 55:91-95.

Groninger, J.W. and D.A. Babassana. 2002. Accelerating planted green ash establishment on an abandoned soybean field. Pages 270-272 in K.W. Outcalt (ed.), Proceedings of the eleventh biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-48.

Haywood, J.D. 1999. Durability of selected mulches, their ability to control weeds, and influence growth of loblolly pine seedlings. *New Forests* 18: 263-276.

Hesse, I.D., W.H. Conner and J.W. Day, Jr. 1996. Herbivory impacts on the regeneration of forested wetlands. Pages 23-28 *in* K.M. Flynn (ed.), Proceedings of the southern forested wetland management and ecology conference. Clemson University, Clemson, South Carolina.

Hook, D.D. 1984. Waterlogging tolerance of lowland tree species of the south. *Southern Journal of Applied Forestry* 8:136-149.

Houston, A.E. and E.R. Bucknor. 1989. Cultural treatments for the establishment of bottomland hardwoods in west Tennessee. Pages 285-288 in J.H. Miller (compiler), Proceedings of the fifth biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana. General Technical Report SO-74.

Howell, K.D. and T.B. Harrington. 2002. Container size and fertilization affect nursery cost and fifth-year field performance of cherrybark oak. Pages 328-331 in K.W. Outcalt (ed.), Proceedings of the eleventh southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-48.

Kennedy, H.E., Jr. 1981a. Bottomland hardwoods research on site preparation, plantation establishment, and cultural treatments, at the Southern Hardwoods Laboratory. Pages 75-78 in J.P. Barnett (ed.), Proceedings of the first biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana. General Technical Report SO-34.

__. 1981b. Foliar nutrient concentration and hardwood growth influenced by cultural treatments. *Plant and Soil* 63:307-316.

__. 1993. Artificial regeneration of bottomland oaks. Pages 241-249 in D.L. Loftis and C.E. McGee (eds.), Oak regeneration: Serious problems, practical recommendations. U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina. General Technical Report SE-84.

Kennedy, H.E., Jr. and R.M. Krinard. 1974. 1973 Mississippi River flood's impact on hardwood forests and plantations. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana. Research Note SO-177.

__. 1985. Shumard oaks successfully planted on high pH soils. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana. Research Note SO-321.

King, S.L. and B.D. Keeland. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. *Restoration Ecology* 7:348-359.

Lantagne, D.O., C.W. Ramm and D.I. Dickmann. 1990. Tree shelters increase heights of planted oaks in a Michigan clearcut. *Northern Journal Applied Forestry* 7:24-26.

Lasher, D.N. and E.P. Hill. 1977. An evaluation of polypropylene mesh tubing as a deer browse deterrent for southern hardwood seedlings. Pages 239-245 *in* Proceedings of the annual conference, Southeastern Association of Fish and Wildlife Agencies.

Ligon, F.K., W.E. Dietrich and W.J. Trush. 1995. Downstream ecological effects of dams. *BioScience* 45:183-192.

Marquis, D.A. and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. U.S. Department of Agriculture Forest Service, Northeastern Experiment Station, Broomall, Pennsylvania. General Technical Report NE-65.

McDonald, P.M. and O.T. Helgerson. 1990. Mulches aid in regenerating California and Oregon forests: Past, present, and future. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Berkeley, California. General Technical Report PSW-113.

McKevlin, M.R., D.D. Hook and A.A. Rozelle. 1998. Adaptations of plants to flooding and soil waterlogging. Pages 173-203 *in* M.G. Messina and W.H. Conner (eds.), Southern forested wetlands: Ecology and management. Boca Raton, Florida: Lewis Publishers/CRC Press.

McKnight, J.S. 1970. Planting cottonwood cuttings for timber production in the South. U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana. Research Paper SO-60.

Miller, J.H. 1993. Oak plantation establishment using mechanical burning and herbicide treatments. Pages 264-289 in D.L. Loftis and C.E. McGee (eds.), Oak regeneration: Serious problems, practical recommendations. U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina. General Technical Report SE-84.

__. 1997. Exotic invasive plants in southeastern forests. Paper presented at Exotic Pests of Eastern Forests Conference, April 8-10, 1997, Nashville, Tennessee.

Ponder, F. 1995. Shoot and root growth of northern red oak planted in forest openings and protected by treeshelters. *Northern Journal Applied Forestry* 12:36-42.

Reed, M.R. and K.W. McLeod. 1994. Planting unconsolidated sediments with flood-tolerant species. Pages 137-146 *in* F.J. Webb, Jr.

(ed.), Proceedings of the twenty-first annual conference on wetlands restoration and creation. Tampa, Florida: Hillsborough Community College.

Savage, L., J. Anthony and R. Buchholz. 1996. Rodent damage to direct seeded willow oak in Louisiana. Pages 340-349 *in* A.G. Eversole (ed.), Proceedings of the 15th annual conference of the Southeastern Association of Fish and Wildlife Agencies.

Schneider, R.L., N.E. Martin and R.R. Sharitz. 1989. Impacts of dam operations on hydrology and associated floodplain forests of southeastern rivers. Pages 1113-1122 in R.R. Sharitz and J.W. Gibbons (eds.), Freshwater wetlands and wildlife. USDOE Office of Scientific and Technical Information, Oak Ridge, Tennessee. CONF-8603101, Symposium Series No. 61.

Schoenholtz, S.H., J.P. James, R.K. Kaminski, B.D. Leopold and A.W. Ezell. 2001. Afforestation of bottomland hardwoods in the Lower Mississippi Alluvial Valley: Status and trends. *Wetlands* 21:602-613.

Schweitzer, C.J., E.S. Gardiner, J.A. Stanturf and A.W. Ezell. 1999. Methods to improve establishment and growth of bottomland hardwood artificial regeneration. Pages 209-214 in J.W. Stringer and D.L. Loftis (eds.), Proceedings of the 12th central hardwood forest conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. General Technical Report SRS-24.

Schweitzer, C.J., J.A. Stanturf, J.P. Shepard, T.M. Wilkins, C.J. Portwood and L.C. Dorris, Jr. 1997. Large-scale comparison of reforestation techniques commonly used in the Lower Mississippi Alluvial Valley: First year results. Pages 313-320 in S.G. Pallardy, R.A. Cecich, H.G. Garrett, and P.S. Johnson (eds.), Proceedings of the 11th central hardwood forest conference. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota. General Technical Report NC-188.

Shankman, D. 1999. The loss of free-flowing streams in the Gulf Coastal Plain. Bulletin *Alabama Museum of Natural History* 20:1-10.

Stanturf, J.A. 1995. Survival and growth of planted and direct-seeded cherrybark oak in the Santee River floodplain after 11 years. Pages 489-494 in J.R. Miller (ed.), Proceedings of the 8th biennial silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-1.

Stanturf, J.A., E.S. Gardiner, P.B. Hamel, M.S. Devall, T.D. Leininger and M.L. Warren, Jr. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. *Journal of Forestry* 98:10-16.

Stanturf, J.A. and H.E. Kennedy, Jr. 1996. Survival and growth of planted and direct-seeded cherrybark oak in South Carolina. Southern *Journal of Applied Forestry* 20:194-196.

Stanturf, J.A. and C.J. Portwood. 1999. Economics of afforestation with cottonwood. Pages 66-72 in J.D. Haywood (ed.), Proceedings of the tenth biennial southern silvicultural research conference. U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-30.

Stanturf, J.A. and S.H. Schoenholtz. 1998. Soils and landforms. Pages 123-147 *in* M.G. Messina and W.H. Conner (eds.), Southern forested wetlands: Ecology and management. Boca Raton, Florida: Lewis Publishers/CRC Press.

Stanturf, J.A., S.H. Schoenholtz, C.J. Schweitzer and J.P. Shepard. 2001a. Indicators of restoration success: Myths in bottomland hardwood forests. *Restoration Ecology* 9:189-200.

Stanturf, J.A., C.J. Schweitzer and E.S. Gardiner. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. *Silva Fennica* 32:281-297.

Stanturf, J.A., C. van Oosten, M. Coleman, D. Netzer, and C.J. Portwood. 2001b. Silviculture and ecology of poplar plantations. Pages 153-206 *in* D. Dickmann, J. Isebrands, and J. Richardson (eds.), Poplar culture in North America. Ottawa, Canada: National Research Council Press.

Williams, H.M. and M.N. Craft. 1998. First-year survival and growth of bareroot, container, and direct-seeded Nuttall oak planted on flood-prone agricultural fields. Pages 300-303 in T. Waldrop (ed.), Proceedings of the ninth biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-20.

Williams, H. and M. Stroupe. 2002. First-year survival and growth of bareroot and container water oak and willow oak seedlings grown at different levels of mineral nutrition. Pages 338-341 in K.W. Outcalt (ed.), Proceedings of the eleventh biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. General Technical Report SRS-48.

Willis, K., C. Woodson and P. Hamel. 1996. Small mammal populations on agricultural land in the Mississippi Alluvial Valley restored to forest, first year results. Paper presented at the annual meeting of the Wildlife Society, Mississippi Chapter, October 17, 1996, Roosevelt State Park, Mississippi.

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Great Trinity Forest Management Plan

HARDWOOD SILVICULTURE

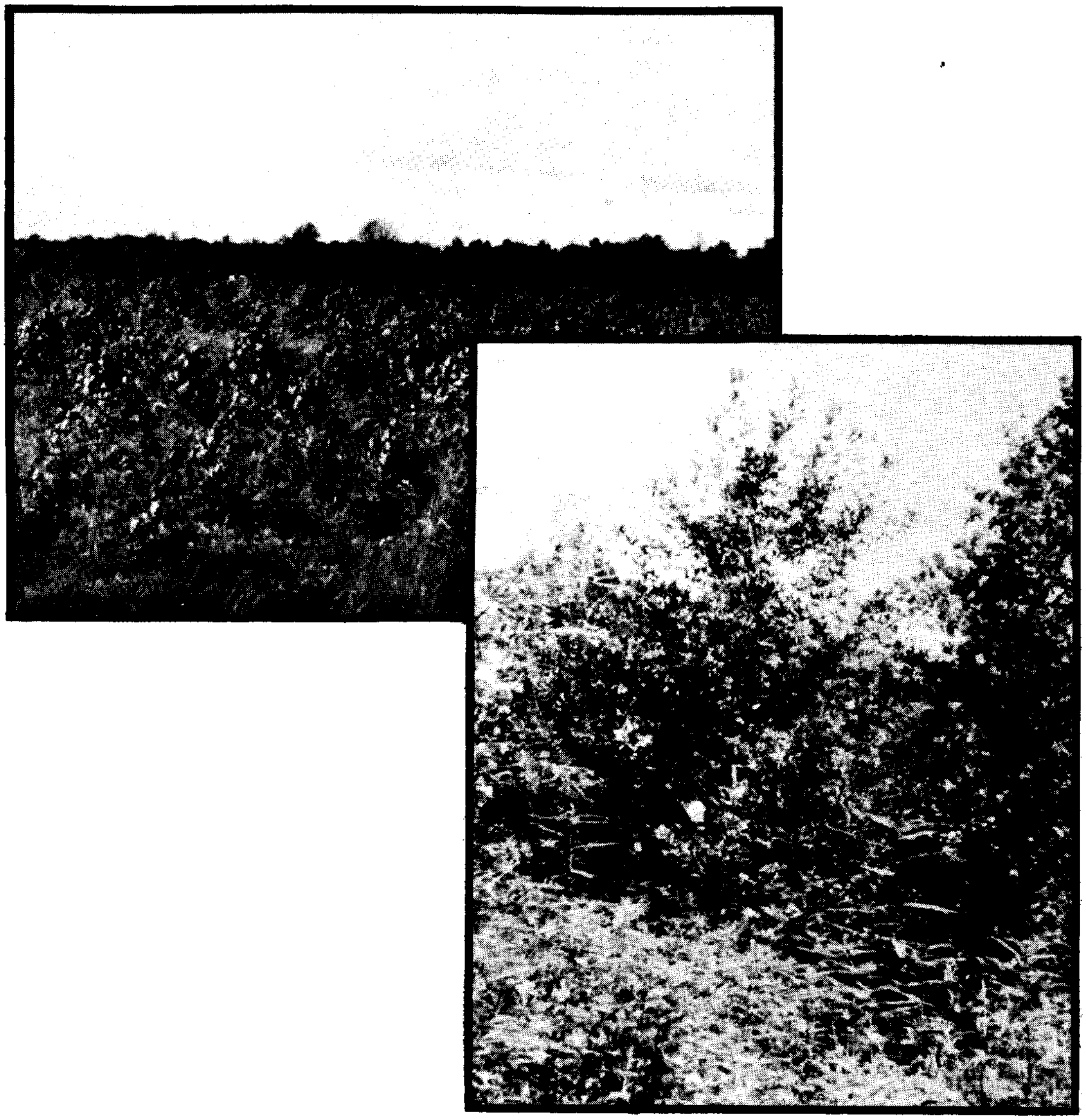
Reestablishment of Bottomland Hardwood Forests on Disturbed Sites: An Annotated Bibliography

(U.S. Fish and Wildlife Service, Biological Report 88 (42), September 1988)

BIOLOGICAL REPORT 88(42)
SEPTEMBER 1988

REESTABLISHMENT OF BOTTOMLAND HARDWOOD FORESTS ON DISTURBED SITES:

AN ANNOTATED BIBLIOGRAPHY



Fish and Wildlife Service
U.S. Department of the Interior

Cover photographs (courtesy of R.J. Haynes):

Upper: Three-year-old direct seeded oaks on old agricultural field in Panther Swamp National Wildlife Refuge, MS.
Lower: Ten-year-old mixed species plantation in Delta National Forest, MS.

Biological Report 88(42)
September 1988

REESTABLISHMENT OF BOTTOMLAND HARDWOOD FORESTS ON DISTURBED SITES: AN ANNOTATED BIBLIOGRAPHY

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PREFACE

The U.S. Fish and Wildlife Service prepared this bibliography to assist those interested in the reestablishment and restoration of bottomland hardwood forests on previously disturbed sites such as abandoned farm land or surface-mined areas. Emphasis of the bibliography is on the Southeastern United States, although entries from other parts of the country are included whenever the authors believed these entries provided useful information. Annotated entries focus on applied restoration of bottomland hardwood ecosystems and "how to" papers concerning silvicultural practices.

Recognition of and interest in the importance and potential opportunities for the restoration of bottomland hardwood forest ecosystems have increased in recent years. Evidence of this includes specific language found in several recently enacted laws (e.g., Food Security Act of 1985, Emergency Wetlands Resources Act of 1986, Water Resource Development Act of 1986). With the increased interest in restoring bottomland hardwood forests, this bibliography should be both timely and useful to environmental planners, managers, and others concerned about this valuable natural resource.

Comments about or requests for this publication should be directed to:

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The authors gratefully acknowledge the assistance of Robert Johnson and Roger Krinard of the U.S. Forest Service, and Russ Lea of the North Carolina State Hardwood Cooperative, each of whom took the time to review drafts of this publication. Also Larry Moore, forester at Tensas National Wildlife Refuge, and Tim Wilkins, manager of the Yazoo National Wildlife Refuge Complex, provided the authors with valuable insight into the information needs of practitioners and would-be practitioners of bottomland hardwood restoration.

Although the three authors wrote this entire document, it would never have reached this final stage without the help of several members of the National Wetlands Research Center editorial staff. Daisy Singleton and Joyce Rodberg performed the difficult task of interpreting three different authors' writing and keyboarding the document. Rudy Krieger and Beth Vairin went through numerous iterations of editing this bibliography, Donna Glass helped design the cover, and Jan Landrum checked the accuracy of many of the citations.

INTRODUCTION

This bibliography was prepared to assist persons interested in the reestablishment of bottomland hardwood forests on previously disturbed sites, such as abandoned farm land or surface-mined areas. For the purpose of the bibliography, bottomland hardwood forests correspond with the "Needle-leaved Deciduous" and "Broad-leaved Deciduous" freshwater (Palustrine) forestedwetlands described in the Wetlands Classification·System used by the U.S. Fish and Wildlife Service (Cowardin et al. 1979). These forests occur primarily within the riverine floodplains of the Midwest and Southeastern United States.

The plant-species composition of bottomland hardwood forests is complex and varied, and is strongly dependent on the varying degrees of inundation (hydroperiod) during the growing season. Over 100 species of woody plants occur in these periodically flooded areas, and all exhibit some degree of adaptation for survival in soils which are inadequately drained and aerated. Commonly recognized species-zonation patterns range from the baldcypress (Taxodium distichum) and water tupelo (Nyssa aquatica) communities associated with longer periods of flooding, to the live oak (Quercus virginiana) and loblolly pine (Pinus taeda) communities on the highest floodplain areas. Depending upon the interaction of numerous ecological factors, many other plant-species associations may occur (see Eyre 1980; Clark and Benforado 1981).

From the mid-1950's through the mid-1970's, about 6 million acres of the Nation's freshwater forested wetlands were lost, principally through agricultural conversions. Although losses vary geographically, over 80% of the original forested wetlands in the Southeastern United States have been lost and about 25% of the remainder may be lost by 1995. In Illinois, about 98% of the bottomland forests have been lost (Harris et al. 1984; Tiner 1984).

Public concern over additional losses of bottomland forests has increased in recent years with better awareness of the many functions and values of these ecosystems (e.g., flood control and water quality protection, fish and wildlife habitat) and the realization of the magnitude of past and continuing losses (Greeson et al. 1978; MacDonald et al. 1979; Brinson et al. 1981; Conner and Day 1982; Wharton et al. 1982; Sather and Smith 1984; Tiner 1984; U.S. Congress 1984). Such changes in attitude have prompted more stringent consideration for the protection of these ecosystems through various regulatory and policy mechanisms (Federal Register 1977; U.S. Congress 1984, 1986a; Barton 1985). For example, Section 906 of the Water Resources Development Act of 1986 (Public Law 99-662) (U.S. Congress 1986b) states that future mitigation plans for Federal water projects should include specific plans to ensure that impacts to bottomland hardwood forests are mitigated in kind, to the extent possible. Also, the Council on Environmental Quality (1985) has stated that "the bottomland hardwoods in the Southeast are of such importance as wildlife habitats, and becoming so scarce, that the principle of full, in-kind replacement should override other considerations."

With increased regulatory emphasis on protection and conservation of wetlands, the need for additional information about the technological ability to reestablish forested wetlands on disturbed sites has also become more apparent. For example, evidence indicates that courts are now willing, and may prefer in some cases, to use information about the cost of carrying out specific vegetation reestablishment efforts in determining a fair assessment of damages in compensation issues (Anonymous 1983). In addition, the lack of a convincingly demonstrated technology has been, and is expected to continue to be, an important consideration in the approval/denial process for various surface-mining activities in forested wetlands (U.S. Bureau of Land Management et al. 1983; Haynes 1984; Haynes and Crabill 1984). The recent emphasis on wetland conservation as presented in the Food Security Act of 1985 (U.S. Congress 1985) may provide opportunities for reestablishment of bottomland hardwood forests on previously farmed and flood-prone areas regulated by the Farmers Home Administration (Office of Federal Register 1987).

Strategies for avoiding net losses of bottomland hardwood forests may include a preservation approach (e.g., land-use restrictions, easements, or land acquisition), or a compensation approach in which losses are replaced or an acceptable substitute provided (U.S. Fish and Wildlife Service 1981). This bibliography focuses on the compensation approach as it relates to the reestablishment of bottomland hardwood forest ecosystems on disturbed sites. Opportunities for such reestablishment occur when the initial loss or modification of the forest community is not permanent and reestablishment methods are technologically feasible. These opportunites may include (1) reestablishment on abandoned, "high-risk" farm lands in flood-prone areas, (2) reestablishment in national forests, wildlife refuges and management areas, flood-control projects, or public lands on which bottomland hardwood forest habitat serves management goals that are determined to be in the best public interest, and (3) reclamation of surface-mined lands.

SCOPE AND ARRANGEMENT

In the initial review of available published literature, over 400 scientific papers, government reports, M.S. and Ph.D. theses, and popular-journal articles were located dealing with one or more factors related to bottomland hardwood restoration. Most of these papers did not discuss restoration specifically, but covered related factors, such as hydrology and flooding effects, soils and nutrients, plant succession and competition, and plant propogation methods. Since time and available staff did not allow the annotation of all the papers that were found, only those references that were thought to contain information of direct value to persons involved in bottomland hardwood restoration were selected for annotation. These annotations form the main section of this report, and are arranged alphabetically by author.

In addition, the bibliography contains non-annotated entries grouped under specific subjects. These entries may be of value to persons requiring more in-depth treatments of specific species or silvicultural methods. Two appendixes are also included. Appendix A lists common and scientific names for bottomland hardwood species covered in this publication and Appendix B catalogues flooding, shade tolerances, and reproductive characteristics of selected bottomland hardwood forest species. Subject and species indexes are provided for cross-referencing of the annotated entries.

Although an attempt was made to include all appropriate citations through May 1988, some papers may have been omitted. We believe, however, that enough entries have been included to make this publication valuable to those involved in the important work of bottomland hardwood restoration.

REFERENCES

Anonymous. 1983. Restoration key to assessing environmental damages liability: interior seeks aid. Restoration Manage. Notes 1(4):14-15.

Barton, K. 1985. Wetlands preservation. Pages 212-264 in R.L. DiSilvestro, ed. Audubon Wildlife Report 1985. New York.

Brinson, M.M., B.L. Swift, R.C. Plantico, and J.S. Barclay. 1981. Riparian ecosytems: their ecology and status. U.S. Fish Wildl. Serv. Biol. Serv. Program FWS/OBS-81/17. 155 pp.

Clark, J.R., and J. Benforado, editors. 1981. Wetlands of bottomland hardwood forests. Developments in agricultural and manage-forest ecology 11: proc. of a workshop; June 1-5, 1980; Lake Lanier, GA. Elsevier Scientific Publishing Company, New York. 402 pp.

Conner, W.H., and J.W. Day, Jr. 1982. The ecology of forested wetlands in the southeastern United States. Pages 69-89 in B. Gopal, R.E. Turner, R.G. Wetzel, and D.F. Whigham, eds. Wetlands ecology and management. National Institute of Ecology and International Scientific Publications, Lucknow Publishing House, Lucknow-226001, India.

Council on Environmental Quality. 1985. Tennessee-Tombigbee Waterway wildlife mitigation plan, Alabama and Mississippi. Fed. Reg. 50(62) (April 1):12850.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv. Biol. Serv. Program FWS/OBS-79/31. 103 pp.

Eyre, F.H., editor. 1980. Forest cover types of the United States and Canada. Soc. of Am. For. Washington, DC. 148 pp.

Federal Register. 1977. Protection of wetlands: executive order 11990. Fed. Reg. 42(May 24):26961.

Federal Register. 1987. Code of federal regulations: agriculture part 1940, subpart G. environmental program. U.S. Department of Agriculture Farmers Home Administration. Washington, DC. pp 307-371.

Fowells, H.A., editor. 1965. Silvics of forest trees of the United States. U.S. For. Serv. Handbook No. 217. Washington, DC. 762 pp.

Greeson, P.E., J.R. Clark, and J.E. Clark. 1978. Wetland functions and values: the state of our understanding. American Water Resources Association, Minneapolis, MN. 674 pp.

Harris, L.D., R. Sullivan, and R.L. Badger. 1984. Bottomland hardwoods: valuable, vanishing, vulnerable. University of Florida, Cooperative Extension Service, Gainesville. 17 pp.

Haynes, R.J. 1984. Summary of wetlands reestablishment on surface-mined lands in Florida. Pages 357-362 in 1984 symposium on surface mining, hydrology, sedimentology, and reclamation. University of Kentucky at Lexington.

Haynes, R.J., and F. Crabill. 1984. Reestablishment of a forested wetland on phosphate-mined land in central Florida. Pages 51-63 in Better reclamation with trees: proceedings of fourth annual conference. Madisonville Community College, Madisonville, KY.

MacDonald, P.O., W.E. Frayer, and J.K. Clauser. 1979. Documentation, chronology, and future projections of bottomland hardwood habitat losses in the lower Mississippi Alluvial Plain. Vols. 1 and 2. U.S. Fish Wildlife Service, Washington, DC.

McKnight, J.S., D.D. Hook, O.G. Langdon, and R.S. Johnson. 1981. Occurrence, shade and flood tolerance and reproductive characteristics of the principal species of the southern bottomland forest. Pages 45-69 in J.R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Publishing Company, New York.

Sather, H.J., and R.D. Smith. 1984. An overview of major wetland functions and values. U.S. Fish Wildl. Serv. Biol. Serv. Program FWS/OBS-84/18. 68 pp.

Tiner, R.W., Jr. 1984. Wetlands of the United States: current status and recent trends. U.S. Fish and Wildlife Service, Habitat Resources, Newton Corner, MA. 59 pp.

U.S. Bureau of Land Management, U.S. Forest Service, and U.S. Fish and Wildlife Service. 1983. Environmental assessment on state of reclamation techniques on phosphate mined lands in Florida and their application to phosphate mining in the Osceola National Forest. U.S. Bureau of Land Management, Alexandria, VA.

U.S. Congress. 1984. Wetlands: their use and regulation. U.S. Congress, Office of Technology Assessment, Washington, DC. 208 pp.

U.S. Congress. 1985. The Food Security Act of 1985. Public Law 99-198, December 23, 1985. U.S. Congress, Washington, DC.

U.S. Congress. 1986(a). Emergency wetlands resources act of 1986. Public Law 99-645, November 10, 1986. U.S. Congress, Washington, DC.

U.S. Congress. 1986(b). Water resources development act of 1986. Pages 4186-4187 in Public Law 99-662, November 17, 1986. U.S. Congress, Washington, DC.

U.S. Fish and Wildlife Service. 1981. U.S. FWS mitigation policy. Fed. Reg. 46(15) (January 23):7644-7663.

Wharton, C.H., W.M. Kitchens, E.C. Pendleton, and T.W. Sipe. 1982, Ecology of bottomland hardwood swamps of the southeast: a community profile. U.S. Fish and Wildl. Serv. Biol. Serv. Program FWS/OBS-81/37. 134 pp.

ANNOTATED ENTRIES

Allen, H.H., and C.V. Klimas. 1986. Reservoir shoreline revegetation guidelines. U.S. Army Corps of Engineers, Environmental and Water Quality Operational Studies, Technical Report E-86-13. 87 pp.

Planning, site preparation, planting, postplanting operations and maintenance, and costs associated with revegetating reservoir shorelines with both herbaceous and woody species are covered. The two main elements of planning are site selection and the choice of plant species and materials. Important site factors to consider include water level fluctuations, bank morphometry, wave climate, animal depredation potential, and soil characteristics. In general, larger-than-average tree seedlings and species that leaf out late should be used to minimize damage from spring floods. Planting of four propagule types for woody vegetation--bare-root, balled-and-burlapped, and containerized seedlings and cuttings--is covered. There is a section on special establishment techniques in erodible environments in the planting chapter; detailed diagrams of most of the techniques are provided. Postplanting operations and maintenance are discussed only briefly. Monitoring is recommended in order to identify needs such as irrigation, fertilization, protection from animals, or cultivation.

Anderson, C.P., P.E. Pope, W.R. Byrnes, W.R. Chaney, and B.H. Bussler. 1983. Hardwood tree establishment in low plant cover on reclaimed mineland. Pages 158-170 in Proceedings of the third annual conference on better reclamation with trees. Purdue University, Terre Haute, IN.

The paper describes a comparison between a reclaimed surface-mined site in Sullivan County, IN, and an unmined reference site which was made to evaluate the effectiveness of hardwood seedling establishment, growth, and related factors. Black walnut and northern red oak seedlings (bare-root and containerized) were planted concurrently with a cover crop of fescue and red clover. Sites were disked, limed, and fertilized. Test areas were treated with herbicide to control ground cover and to assess the competitive effects of ground cover on seedling establishment and growth. After two growing seasons, red oak seedlings exhibited lower survival and less net height growth than black walnut seedlings. Individual container-produced seedlings survived better than bare-root seedlings. Herbicide use to reduce ground cover competition effectively improved black walnut survival and growth, but had no significant effect on red oak. Selected physical and chemical properties of the growth media are discussed.

Anonymous. 1984. Turning farmland into forests. Pages 10-11 in Woodlands for wildlife. Mississippi Department of Wildlife Conservation, Jackson, MS.

A large-scale, lo-year program to reforest nearly 1,000 acres of old farm fields on the Malmaison Wildlife Management Area in Mississippi is covered. Since 1981, about 100 acres/year have been direct seeded with oak acorns collected by wildlife area managers around Mississippi and shipped to Malmaison. Species planted include water, willow, and cherrybark oak. Sowing is done with a modified two-row John Deere planter; 40 acres/day can be planted. Researchers from the U.S. Forest Service Southern Forest Experiment Station in Stoneville, MS, are monitoring the results of the plantings. They report that germination and seedling survival appear to be adequate in most areas planted to date.

Anonymous. 1986. Results of oak direct seeding are promising. Tree Talk 7(2):9-11.

This article describes an oak direct-seeding project, which began in November 1981, on about 1,100 acres of old farmland in the Panther Swamp National Wildlife Refuge, in Yazoo County, MS. Species planted include water, willow, and Nuttall oak. Two planting machines were used: a modified antique "belly mount" cotton planter was used on heavy high-shrink Sharkey clay areas; and a converted John Deere Maxi-Merge 7,100 planter was used for planting unprepared ground that contained agricultural debris. Germination of willow oak began during April 1982 and Nuttall oak germination occurred from mid-May throughout the summer. Survival and germination were reported to be adequate. Although only oaks *were* planted, invader species, such as pecan, water hickory, persimmon, sugarberry, honeylocust, and green ash, are expected to be components of the mature stands and should enhance the overall value of the forest for wildlife.

Ashby, W.C., C.A. Kolar, and N.F. Rogers. 1980. Results of 30-year-old plantations on surface mines in the central states. Pages 99-107 in Proceedings of trees for reclamation. U.S. Forest Service General Technical Report NE-61, Broomall, PA.

This report indicates that after at least 30 years, 28 species of trees have been grown successfully on surface-mined lands in the Central States. Many of the previously planted stands were vigorously invaded by volunteer trees, as well as other plants and animals. The success of a species was affected by geographic location, type of rooting medium, and whether species were planted alone or interplanted. Species reviewed included maples, green ash, black walnut, sweetgum, tulip tree (yellow-poplar), pines, sycamore, cottonwood, oaks, and black locust. Green ash exhibited the highest survival rate of any species. Sweetgum showed both good growth and survival. Black walnut and tulip trees (yellow-poplar) were very site sensitive; growth and survival varied substantially due to variations in soil pH, drainage, and other factors. Sycamore and cottonwood yielded some of the largest trees although tree form was poor, and volunteer trees of these species often equaled or exceeded planted trees in size. Plantings of various oak species were successful in some locations; no planting failures are reported in the paper. Black locust showed rapid early growth before succumbing to the locust borer (Mesacvllene robiniae). Major invaders under established tree cover were elms, hackberry, and boxelder. Other important local invaders were black cherry, ashes, pin oak, shingle oak, and sassafras. Many areas exhibited a dense herbaceous layer. Common shrubs were dogwoods, grape, and sumac.

Ashby, W.C., W.G. Vogel, and C.A. Kolar. 1983. Use of nitrogen-fixing trees and shrubs in reclamation. Pages 110-118 in Proceedings of the third annual conference on better reclamation with trees. Purdue University, Terre Haute, IN.

The importance of nitrogen-fixing trees and shrubs to the establishment of other trees, and the advantages and disadvantages of using nitrogen-fixing species are discussed. Black locust, European alder, and autumn olive have been the most widely used species in mined-land reclamation. Nitrogen-fixing species can contribute to greatly accelerated growth and invasion of other trees. Black locust and European alder experience die-back and mortality after 5 or more years. The locust is often attacked by the locust borer, though some stands escape. Locust sprouts vigorously from roots and sprouts grow well if not shaded. The reasons for alder mortality are not well understood. As a disadvantage, locust and autumn olive often produce dense thickets that are difficult to move through for interplanting or underplanting other trees. Alder may exhibit excessive competitiveness on good sites; autumn olive may overtop young trees if planting densities are not carefully controlled, and the seeds can be widely distributed by birds to other areas where unwanted establishment may occur. The author notes that an extensive literature documenting the values of nitrogen-fixing species is available.

Baker, J.B. 1977. Tolerance of planted hardwoods to spring flooding. Southern Journal of Applied Forestry 1(3):23-25.

Inundation of cottonwood cuttings and seedlings (1-0 stock) of sweetgum, water tupelo, American sycamore, and green ash were studied and detailed in this article. Cuttings and seedlings were planted on a Sharkey clay site near Stoneville, MS, in two consecutive years in 25-tree plots. After the trees had leafed out in May, 3 ft of water was pumped onto the plots, all trees were completely inundated for 4 weeks, and then the water was removed. Water tupelo, green ash, and sycamore were consistently most tolerant of spring flooding; survival was about 90%. Cottonwood was the least tolerant of flooding; an average of only 24% of the cuttings survived. All species except green ash lost their leaves each year during the flooding period. Average height growth for surviving seedlings one season after flooding was highest for cottonwood (3.7 ft), followed by green ash (2.8 ft), sycamore (2.4 ft), water tupelo (1.8 ft), and sweetgum (1.2 ft).

Baker, J.B., and W.M. Broadfoot. 1979. A practical field method of site evaluation for commercially important southern hardwoods. U.S. Forest Service General Technical Report SO-26, New Orleans, LA. 51 pp.

This report provides a method and guide for evaluating the suitability of sites for 14 hardwood species: cottonwood, green ash, pecan, sycamore, sweetgum, yellow-poplar, hackberry, sugarberry, cherrybark oak, Nuttall oak, Shumard oak, water oak, willow oak, and swamp chestnut oak. The method is based on the four most important determinants of hardwood growth: soil physical condition, moisture availability during the growing season, nutrient availability, and soil aeration. Based on the percentage of maximum tree growth attributable to each of these factors, a site quality rating (SQR) is assigned for best, medium, and poor conditions. The rating for each major factor is further divided according to the relative influences of soil-site properties; for instance, overall nutrient availability is assessed by rating geologic sources, past soil use, percent organic matter, depth of topsoil, soil age, and pH. All soil factors are tabulated and rated. Values from the table are summed to assess the site's suitability for a particular species. Estimates of potential productivity for cottonwood, sweetgum, and sycamore are also,given.

Bates, A.L., E. Pichard, and W.M. Dennis. 1978. Tree plantings--a diversified management tool for reservoir shorelines. Pages 190-194 in Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Proceedings of a symposium; U.S. Forest Service, Washington, DC.

This paper reports on studies that have been conducted since 1935 on shoreline plantings of water-tolerant tree species along periodically flooded or dewatered shoreline within the mainstream and tributary reservoirs of the Tennessee Valley Authority system. Baldcypress was determined to be the most desirable species for planting in the fluctuation zone of reservoirs because of its rapid growth rate and ability to withstand prolonged flooding even in the seedling stage. Recently, however, plantings of baldcypress have been detrimentally affected by high populations of beaver. Beaver populations along with competition from herbaceous species in the upper portion of the fluctuation zone seemed to be major limiting factors to successful plantings. Shoreline plantings of water-tolerant species provided the potential for shoreline stabilization, better habitat for desirable wildlife, a biological mosquito control method, replacement of wetlands lost in reservoir construction, and an aesthetically'pleasing shoreline landscape.

Bedinger, M.S. 1971. Forest species as indicators of flooding in the lower White River Valley, Arkansas. Pages C248-C253 in Geological survey research 1971. Chapter C. U.S. Geological Survey Professional Paper 750-C, Washington, DC.

This study indicates that flooding is the dominant environmental factor determining tree species distribution within the lower valley of the White River, AR. The relationship between flooding and tree species occurrence was sufficiently distinct to permit determination of flood characteristics at a given site by evaluation of forest-species composition. On sites flooded 29%-40% of the time, the dominant species were water hickory and overcup oak. On sites flooded 10%-21% of the time, species included Nuttall oak, willow oak, sweetgum, sugarberry, and American elm. Sites subject to flooding at intervals of from 2 to 8 years included southern red oak, shagbark hickory, and blackgum. The presence of blackjack oak marked areas not flooded in historic times.

Bonner, F.T. 1964. Seeding and planting southern hardwoods. Pages 28-40 in Proceedings of the Auburn University hardwood short course; Auburn, AL.

This paper summarizes the state of knowledge about southern hardwood seeding and planting as of 1964. A table is presented which includes planting information on cottonwood, sweetgum, green ash, sycamore, yellow-poplar, oaks, black walnut, water tupelo, and baldcypress. Information given includes recommended pruning length for roots, recommended top length, best root-collar diameter, adaptability to machine planting, response to fertilizer, usual first-year growth, suitability for wet sites, and susceptibility to animal and insect damage. In addition to the table, the paper includes sections on protection, cultivation and weed control, and direct seeding. Protection of sweetgum, oaks, green ash, and yellow-poplar seedlings can be difficult in old-field plantings, where they are susceptible to damage by rabbits and other rodents. No repellant is available yet for application to seedlings or cuttings. Protection from livestock and fire is essential for good results. Cultivation is very important in cottonwood plantations; cross-disking is the best method. Black walnut and sycamore also have been shown to benefit from weed control. Direct-seeding results to date have been erratic. Rodents have been responsible for most direct-seeding failures of oaks, and have also damaged black walnut seed. Some seeds, such as those of the red oaks and white ash, may remain dormant for a year or more after sowing.

Bonner, F.T. 1966. Survival and first-year growth of hardwoods planted in saturated soils. U.S. Forest Service Research Note SO-32, New Orleans, LA.

This study documents the growth of sycamore, sweetgum, and Nuttall oak in poorly-drained saturated soils typical of Mississippi River batture and slackwater clay areas (Commerce silt loam and Sharkey clay). One-year-old seedlings in pots of these two soils were kept under saturated conditions and monitored from February until August for various aspects of root and shoot growth. Timing of bud-break, initiation of height growth, and seedling survival were not influenced by either soil type or saturation. Saturation did decrease terminal, stem diameter, and root growth. At least 10 weeks of continuous saturation were required to produce large decreases in growth. Sycamore seedlings exhibited the best overall growth; however, terminal growth of the seedlings was more greatly impacted by saturation than in the other two species. Root growth was suppressed in Nuttall oak and sweetgum; sycamore roots grew twice as much in clay soil as in silt loam. Stress on the seedlings was also evident in measures of water balance, especially in silt loam.

Bonner, F.T. 1977. Handling and storage of hardwood seeds. Pages 145-152 in Proceedings of the second symposium on southeastern hardwoods; U.S. Forest Service State and Private Forestry, Atlanta, GA.

Techniques for seed storage and handling for a number of bottomland hardwood species are described. Sweetgum, sycamore, green ash, white ash, and yellow-poplar seeds should be stored dry (moisture content 6%-8%), as well as seeds from fruits or drupes (such as black cherry, dogwood, sugarberry, and water tupelo). A table of oven temperatures and drying times is given. Red and white oak acorns are stored moist; the seeds become non-viable when the moisture content drops to 25%-30%. Treatment of acorns for removal of insect larvae is not recommended. Dried seeds may be stored at temperatures of 0-5 °C for long periods of time, or at higher temperatures if they are to be sowed during the next spring. Sweetgum, sycamore, yellow-poplar, green and white ash, and black cherry may be stored in this manner for up to 5 years. Water tupelo, shagbark hickory and cottonwood seeds can be stored for 2 to 3 years. Acorns should be maintained at 35%-45% moisture at temperatures between freezing and 2 °C in 4-mil-thick polyethylene bags to allow gas exchange. The more dormant the oak, the longer the acorn can be stored. Red oak acorns store much better than those of the white oak group. The control of moisture content in seeds is critical to avoid damage from lipid autooxidation (below 5% moisture), fungal growth (10%-18%), or heat from respiration (above 18%). Relative humidity in the storage area can be controlled, but is expensive; storing seeds in moisture-proof containers is more economical.

Bonner, F.T. 1984. Testing for seed quality in southern oaks. U.S. Forest Service Research Note SO-306. New Orleans, LA. 6 pp.

This paper describes various experiments on measurement of acorn vigor carried out at the Forestry Sciences Laboratory in Starkville, MS. A variety of techniques are discussed, including the standard laboratory germination test, cutting tests, radiography, tetrazolium staining (TZ test), germination rate tests (peak value (PV) and mean germination time (MGT)), and leached conductivity tests. In 1978, five lots of water oak, collected from 1975 to 1978 were randomly sampled for three types of tests: standard laboratory germination test, TZ, and the PV. These tests results were compared with indicators of seed and seedling performance in nursery beds. All tests clearly showed which lots were the best and the poorest quality. Results of the standard laboratory germination TZ tests appear to have been correlated with nursery germination and growth, but the number of lots precluded a definitive test. In 1982, multiple lots of white oak, water oak, and cherrybark oak were selected for the standard laboratory germination, TZ, PV, and MGT tests. The test results were again compared with several indicators of seedling performance in nursery beds and showed that TZ testing gave the best results for cherrybark oak, followed by the PV test; PV and MGT tests were best for water oak. No tests were significantly correlated with nursery germination of white oak. Seed vigor tests could not predict oak seedling performance after germination. Tetrazolium staining test results were significantly correlated with results of the standard laboratory germination test for white and cherrybark oaks, but not water oaks. In spite of the mixed results, seed quality testing is definitely recommended.

Bonner, F.T. 1986. Good seed quality -- how to obtain and keep it. Pages 31-36 in Northeastern area nurserymen's conference; State College, PA.

This paper contains recommendations for the collection, processing, storage, and planting of oak acorns and small "orthodox" seeds (such as sweetgum, sycamore, and yellow-poplar). Oak acorns need to be stored at higher moisture contents and thus are treated differently from the so-called orthodox species. Whereas the orthodox seeds can be dried to moisture contents of below 10%, white oak acorns will die at moisture contents below 35% and red oaks, below 25%. Both types of seed should be collected only when mature; many orthodox seeds reach maturity in the early fall, but, in general, collection should be delayed until the seeds have dried somewhat. Cut-and-float tests are recommended for acorns since weevil infestations may require additional collection efforts. Three key points for acorn storage are: (1) keep acorns moist; (2) keep them cool (1-3 °C); and (3) do not store them in airtight containers. Stratification periods are recommended for nine oak species. If stored correctly, orthodox seed may remain viable for at least 3 years. At best, white oak acorns should be stored only over one winter, and ideally should be planted the same fall they are collected. Most red oaks can be stored up to 3 years, but viability may fall 50% in this time The paper concludes with nine general considerations for assuring good seed 'quality.

Bonner, F.T., and J.A. Vozzo. 1985. Seed biology and technology of Quercus. U.S. Forest Service General Technical Report SO-66, New Orleans, LA. 21 pp.

This monograph is divided into two parts--current biological knowledge and handling and management of acorns. The first section briefly covers the taxonomy of the genus Quercus, and describes the anatomy, metabolism, dormancy, and predators of oak seeds in detail. The second section covers seed collection, cleaning and conditioning, treatment for insects, storage, stratification, and testing. All oaks belong to one of two subgenera of Quercus, which are generally referred to as red and white oaks. Both biological characteristics and some aspects of handling and management of acorns differ substantially, making the distinction between these groups important for planting operations. Acorns should be collected as soon as they are mature, which in the Midsouth is usually from late October to early November. Indicators of maturity are provided for both subgenera, and collection methods are covered briefly. It is very important to prevent excessive drying--loss of moisture should not exceed 5%. Treatment for insects should be done with caution since common treatment methods such as soaking in hot water and fumigating can also harm the acorns. Storage techniques vary between the subgenera. In general, white oaks cannot be successfully stored more than 4-6 months, and the best recommendation is to store them in the ground by planting them in the fall. A good method of storing red oaks is to keep them in polyethylene bags with a wall thickness of 4-10 mil at a temperature near, but above, freezing (1-3 °C). Recommended stratification periods for selected red oaks are provided, and some common test procedures are described.

Briscoe, C.B. 1957. Diameter growth and effects of flooding on certain bottomland forest trees. Ph.D. Dissertation. Duke University, Durham, NC.

This study covers tree diameter growth and the effects of flooding on seedlings of water tupelo, sweetgum, loblolly pine, laurel oak, baldcypress, water oak, northern red oak, cherrybark oak, slash pine, and swamp tupelo on seven types of physiographic sites in southeastern Georgia. Seedlings of water tupelo, swamp tupelo, northern red oak, cherrybark oak, and slash pine were treated to determine the effects of flooding on growth. All species tolerated up to 51 days of flooding and submersion (the longest period allowable in the experiment). Tolerance to flooding was related to the frequency of flooding at the different sites where the species were naturally found in southeastern Georgia. Submersion of the seedlings reduced growth more than just flooding the soil. Tolerance to flooding increased with age of the seedlings and decreased with the duration of the flooding event. Water temperature affected growth; seedling growth ceased at water temperatures of 41 °F and seedlings suffered some (reversible) damage at holding temperatures of 95 °F. Root growth was more reduced by flooding than was shoot growth. Slash pines suffered mortality after flooding due to a seed-borne fungus. Some swamp and water tupelo mortality due to insect larvae was observed.'

Briscoe, C.B. 1961. Germination of cherrybark and Nuttall oak acorns following flooding. Ecology 42(2):430-431.

The article details germination experiments on cherrybark and Nuttall oak acorns previously kept in cold, moist stratification for 4 months. The acorns were divided into 100-seed lots and four lots were randomly assigned to each of 10 treatments: no flooding; flooding in open-mesh bags in swamp water or tap water for 8, 18, and 34 days; and flooding in sealed containers of tap water for the three periods. Temperature of all the waters ranged from 37-40 °F. Following these treatments, acorns were germinated in wooden flats filled with vermiculite. The results indicated a significant interaction of species and flooding period, but no significant differences based on type of water used. Cherrybark oak germination was significantly lowered by the 34-day submersion period; germination averaged 44% after 8 days, 41% after 18 days, and 26% after 34 days. Nuttall oak was not affected by flooding period, and germination for all waters combined varied from 41% to 44%. There was some indication that the germination percentage for Nuttall oak was higher for large than for small acorns.

Briscoe, C.B. 1963. Rooting cuttings of cottonwood, willow, and sycamore. Journal of Forestry 61(1):51-53.

The report covers a study which took place on first bottoms of the Atchafalaya River in southern Louisiana. Cuttings of cottonwood, willow, and sycamore were obtained from natural stands and were collected each month from October 1957 through September 1958 (except August). Trees were cut near the ground with a machete; the basal 16-inch length was the butt-cut. The majority of the cuttings had a diameter inside bark of 0.3-0.8 inches, with a total range of 0.2-1.9 inches. Cuttings were set in a nursery bed on the same day they were collected; subsets of each species were removed each month to check for rooting. All species rooted every month, but November was the best month for cottonwood (92% of cuttings obtained and planted in November rooted) and March was best for willow and sycamore (100% of cuttings of both species rooted). October to December was the best period for rooting cottonwood, and January to March was best for sycamore, while willow did just as well on average in both periods. Butt-cuts rooted better (66% overall) than second-cuts (54%). Willow cuttings grew the fastest; sycamore grew the slowest. Butt-cuts of willow averaged 3.0 ft in height by the end of the study (about 5-6 months of growth), compared to 2.1 ft for cottonwood, and 1.4 ft for sycamore.

Broadfoot, W.M. 1976. Hardwood suitability for and properties of important Midsouth soils. U.S. Forest Service Research Paper SO-127, New Orleans, LA. 84 pp.

This document updates and expands previous information about important Midsouth soils and their suitability for hardwoods. Forty tables describe the properties of each soil, give management suggestions, and indicate occurrence, suitability, and productivity of various species. Of the 40 soils described, 16 are found primarily in the Southern Mississippi Valley Alluvium, 12 in the Silty Uplands, 9 in the Coastal Plains, and 3 in the Blackland Prairies.

Broadfoot, W.M., and R.M. Krinard. 1961. Growth of hardwood plantations on bottoms in loess areas. U.S. Forest Service Tree Planters' Notes 48:3-8.

This article, with pictures and detailed captions, briefly describes 17- to 25-year-old hardwood plantations within the loess soil belt of Mississippi and Tennessee. A 17-year-old baldcypress plantation and a 6-year-old cottonwood plantation are included for comparison. All plantations were on abandoned farm land in stream bottoms or branch heads, and were established with 1-0 nursery seedlings on a 6 by 6 ft spacing, (the cottonwood plantation was established from cuttings planted on a 9 by 9 ft spacing). In addition, two sweetgum plantations and one each of southern red oak, white oak, water oak, swamp chestnut oak, yellow-poplar, water tupelo, green ash, and river birch are depicted. At age 21, the three largest white oaks averaged 9.2 inches in dbh and 50 ft in height. After 25 years the yellow-poplar plantation had 61% survival and an average diameter of 5.3 inches. Data are also given for age, survival rate, dbh, and height for sweetgum, water oak, willow oak, swamp chestnut oak, green ash, cottonwood, and baldcypress. No data were collected for southern red oak or river birch.

Clewell, A.F. 1981. Vegetational restoration techniques on reclaimed phosphate strip mines in Florida. Wetlands 1:158-170.

A portion of this paper discusses preliminary results for forest reestablishment on phosphate-mined lands in Florida. Four methods of swamp restoration were evaluated: (1) planting of tree seedlings (primarily with bare roots rather than potted); (2) transplanting of saplings from natural swamps with a tree spade; (3) mulching, using topsoil from natural swamps; and (4) natural colonization. The author noted that the planting of tree seedlings promises the partial success of forest reestablishment; helps to overcome any inadequacy of natural seed sources; and is considered inexpensive, as long as a mechanical tree planter is used. It was pointed out that unavailability of preferred nursery stock could be a serious problem, Tree spading of saplings up to about 8 cm in diameter from natural swamps to adjacent reclaimed lands can be accomplished, though often with limited success. An operator can transplant about 200 trees a week using tree-spading equipment; however, the operation is limited to soils firm enough to support the equipment. Swamp mulching holds promise in special limited situations; mulching in strips or piles between planted trees is recommended. For colonization by natural invasion, an inverse correlation between distance from the nearest natural seed source (which in Florida is typically a riparian forest) and the number of species present was noted. Limitations to planting methodologies include cost, time requirements needed to satisfy regulatory requirements, and the self-sustaining capability of the species used.

Clewell, A.F. 1983. Riverine forest restoration efforts on reclaimed mines at Brewster Phosphates, central Florida. Pages 122-133 in D.J. Robertson, ed. Reclamation and the phosphate industry. Proceedings of a symposium; Clearwater Beach, FL; 26-28 January, 1983. Florida Institute of Phosphate Research, Bartow.

This paper provides the following summary statements about major forest reestablishment issues within the central Florida phosphate mining area: (1) Prescribed vegetational restoration activities are essential to restoring plant communities that closely resemble those of natural riverine forests; (2) Previous studies strongly suggest that natural dissemination of seeds can be incorporated into a restoration plan for a site bordering a natural seed source; (3) Bare-root seedlings can be used in restoration, but may not always yield satisfactory results; (4) Tree-spading may be advantageous in some situations. If tree-spading is attempted, irrigation may accelerate the recovery of the root system. Additional information regarding the value of tree-spading in forest restoration is needed; (5) Preliminary results from studies have suggested that direct seeding is possible for some species, but percentage of germination and survival may be low; (6) Mulching seems to be helpful in restoring riverine forests as long as high soil moisture is maintained; thus, irrigation may be required. Also, mulching (in this case topsoil spread about a foot in depth and obtained from a riverine forest) introduces many species of plants; (7) Weeds can result in severe competition for tree seedlings and young saplings, although weeds can provide shade and protection from wind. The author recommends additional study of several methods for partial weed control; (8) The author concludes that a riverine forest could be restored, but that successful restoration is dependent on using a combination of methods applicable to the specific situation.

Conner, W.H. 1988. Natural and artificial regeneration of baldcypress in the Barataria and Lake Verret Basins of Louisiana. Ph.D. Dissertation. Department of Forestry, Wildlife and Fisheries Science, Louisiana State University, Baton Rouge.

This dissertation covers natural regeneration occurring from 1982-87 and the results of four planting trials of baldcypress in southern Louisiana. Overall, natural regeneration was poor in both basins studied, and artificial regeneration was largely unsuccessful due to nutria depredation. In three of the trials, most unprotected seedlings planted in both logged and unlogged stands were quickly destroyed by nutria. Vexar plastic seedling protectors were tried, but at best only slowed the rate of seedling destruction slightly. Chicken wire fences were used to protect one planting, and survival ranged from 64% to 91%, compared to about 15% for the other trials. In the fourth trial, baldcypress seedlings were planted in a seasonally flooded crawfish pond in February and July for two consecutive years. February-planted seedlings that experienced one growing season before flooding had the best survival and growth. After 3 years, annual growth rates of February- and July-planted seedlings were similar.

Conner, W.H., and J.R. Toliver. 1987. Vexar seedling protectors did not reduce nutria damage to planted baldcypress seedlings. U.S. Forest Service Tree Planters' Notes 38(3):26-29.

This article covers the results of a baldcypress planting trial in southern Louisiana, which was designed to test the effectiveness of Vexar plastic seedling protectors as a deterrent to nutria depredation. Five areas of typical baldcypress-tupelo forest--four of which had been logged recently--were planted with 1-year-old seedlings, and half the seedlings in each area were protected with Vexar seedling protectors. The seedling protectors slowed down the rate of destruction somewhat, but after 3 months, 85% of the protected seedlings and 87% of the unprotected seedlings had been destroyed by nutria.

Dickson, R.E., and T.C. Broyer. 1972. Effects of aeration, water supply, and nitrogen source on growth and development of tupelo gum and baldcypress. Ecology 53(4):626-634.

Three separate experiments on water tupelo and baldcypress are summarized. The experiments were designed to (1) compare the relative effects of saturated and unsaturated soil, aeration within the saturated soil, and nitrogen fertilizer source on growth; (2) determine the effects of aeration and water availability on internal plant moisture stress and growth; and (3) compare the effects of four soil-moisture regimes on internal moisture stress and growth. Seedlings were grown in 7-inch clay pots, with four or five seedlings per pot. Five soil-water regimes were more sensitive to anaerobic, saturated soil. Nitrogen fertilization produced more growth compared to no-nitrogen fertilization in saturated soil, but had no significant effect on seedlings in unsaturated soil. Urea produced more growth than nitrate for baldcypress, while the opposite was true for water tupelo. In general, baldcypress was more responsive to fertilization than water tupelo.

DuBarry, A.P., Jr. 1963. Germination of bottomland tree seed while immersed in water. Journal of Forestry 61(3):225-226.

The article details tests of seeds germinated in water. The seed of baldcypress, Carolina ash, green ash, buttonbush, sycamore, swamp tupelo, water tupelo, American elm, and sweetgum were subjected to 30 days of immersion in water to test germination. Testing was done in open-top, aluminum-foil containers filled with about 2 inches of tap water. Water temperature for the immersion treatments ranged from 75 to 90 "F, and constant, artificial light was maintained throughout the test period. Control groups consisted of seeds placed in sponge-type germinators, which kept seeds moist but not completely immersed. In addition, representative samples (whole seed) of each species were analyzed for nitrogen-free-extract (NFE) to evaluate its role in the germination process. Immersion in water was found to have a beneficial affect on soft-coated seeds with NFE contents of 25% or more. Only baldcypress and water tupelo failed to germinate after 30 days. Other species ranged from 21.5% germination (sweetgum) to 86.5% (buttonbush).

Erwin, K.L., G.R. Best, W.J. Dunn, and P.M. Wallace. 1985. Marsh and forested wetland reclamation of a central Florida phosphate mine. Wetlands 4:87-104.

This journal article discusses wetlands reestablishment on a 148-ha project site of phosphate-mined land in central Florida, of which 61 ha of wetlands and 87 ha of uplands were reclaimed in 1981-82. The wetlands were designed to create freshwater marsh, hardwood swamp, and open water. About 66,000 trees (12 wetland species) were planted. Tree seedling survival and condition as a function of type of seedling, season, and water depth were determined. Overall seedling mortality in the reclamation area was small. Carolina ash had the highest net survival (98%) and growth in height. Other species that exhibited high survival included red bay (90%), black gum (90%), sycamore (90%), Florida maple (86%), and sweet bay (83%). Following a very poor initial survival rate (58%), cypress seedlings gradually recovered through root stock sprouting to a 78% survival rate. Species with relatively low initial survival included Dahoon holly (56%), loblolly bay (44%), and laurel and live oaks (12%), although the data for the oaks may not be valid because of the small number of individuals in the sampling population. Growth rates of cypress seedlings were higher at low-water levels (e.g., <30 cm); it was recommended that water conditions during the first and second growing seasons should be kept low to increase height growth and survival. Competitive growth of some marsh plants (e.g., cattail, marsh willow) appeared to retard seedling growth and/or survival ability. However, if seedlings were successful in surviving the competition, their growth rate was high.

Ettinger, W., and C. Yuill. 1982. Sand and gravel pit reclamation in Louisiana: creation of wetlands habitats and its integration into adjacent undisturbed bayou. Pages 109-114 in Wildlife values of gravel pits. Agricultural Experiment Station Miscellaneous Publication 17. University of Minnesota, St. Paul.

This paper describes a reclamation plan for an area surface mined for sand and gravel in Webster Parish, LA. The goal of the reclamation plan was to convert the barren unreclaimed site into a diverse assemblage of bottomland forest and shallow and deeper water habitat integrated into the Bayou Dorcheat and Lake Bistineau ecosystems. Important planning elements were water-level considerations, regrading and reshaping spoil, and revegetation. A limited program of tree planting was proposed. On areas above a typical yearly high-water mark, species to be planted included hickory, pecan, Shumard oak, and willow oak. Recommended species on seasonally flooded areas were green ash, overcup oak, water hickory, and water oak. As islands and emerging areas stabilize, baldcypress and other bottomland hardwoods were expected to colonize the site from adjacent undisturbed areas. As of 1982, the plan was being implemented but follow-up monitoring data were not available.

Finn, R.F. 1958. Ten years of strip-mined forestation research in Ohio. U.S. Forest Service Central States Forest Experiment Station Technical Paper 153. Columbus, OH. 38 pp.

This paper summarizes the results of 10 years of planting studies on coal strip-mined land in Ohio, and clearly shows that a variety of trees (including bottomland hardwood types) and forage plants can be successfully grown. Factors studied included species adaptation, mixed plantings, direct seeding and other planting methods, and the effect of grading on planted trees. Generally, poor results were obtained from direct seeding; grading retarded height growth of most planted trees.

Fletcher, S.W. 1986. Planning and evaluation techniques for replacement of complex stream and wetland drainage systems. Pages 195200 in Proceedings: new horizons for mined land reclamation. American Society for Surface Mining and Reclamation, Princeton, WV.

This paper describes a planning approach for replacing stream and wetland ecosystems on phosphate-mined lands in central Florida where existing systems are characterized, and hydrologic, soil, and vegetational profiles are developed for each community type and stream reach. Postmining plans are developed with consideration of premining conditions. The reclamation plan includes a series of iterative steps to allow reestablishment of each profile toward optimum configuration. Flow barriers, contouring, and other devices are designed to create proper hydroperiod conditions for each community type.

Fowells, H.A., editor. 1965. Silvics of forest trees of the United States. U.S. Department of Agriculture Handbook No. 271. Washington, DC. 762 pp.

This handbook is an edited compendium of silvical papers on tree species of commercial importance. A total of 127 species are covered, including most of the major bottomland hardwood species. The information provided for each species includes habitat conditions (climate, soils and topography, and associated trees and shrubs), life history (reproduction and early growth, and sapling stage to maturity), and races and hybrids. (Authors' note: a new edition of this handbook is due to be published in 1988).

Francis, J.K. 1985. Bottomland hardwood fertilization--The Stoneville Experience. Pages 346-350 in Proceedings of the third biennial southern silvicultural research conference; Atlanta, GA.

Results of several fertilization studies with cottonwood and other bottomland hardwood species and species mixes are discussed. In eight studies, cottonwood plantations were fertilized with rates of nitrogen (NH_4NO_3) ranging from 0 to 600 lb/acre. In some of the studies, P and K were added to a treatment, and lime was included in one study. The best rates of N fertilizer were 150 and 300 lb/acre. Most of the responses to fertilizer occurred in the first year of the trials, and by the third year no further response was evident. Evidence indicates that the best time to fertilize cottonwood may be March; also, cottonwood may be more likely to respond to fertilizer at age 4 than at younger ages. Benefit was not derived from the addition of P, K, or lime in any of the trials. The most important cause of success or failure of a treatment was site history. Old field sites were much more responsive to fertilization than plantations established on sites recently cleared of forest. Plantations on medium-textured soils, such as Commerce or Convent, responded more to fertilization than plantations on Sharkey or Urbo soils. Results with other bottomland hardwoods were similar in most cases. Generally, the best response was obtained on old fields with N, or N and P. Responses in most cases were not high enough to justify the costs of fertilization given current forest-product prices. The author concluded that fertilization should be limited to special cases, which are not yet well-defined.

Fung, M.Y.P. 1986. Ground cover control with herbicides to enhance tree establishment on oil sands reclamation sites. Pages 179-182 in Proceedings of the symposium on new horizons for mined land and reclamation. American Society for Surface Mining and Reclamation, Princeton, WV.

The paper covers a common problem encountered during the initial phase of woody plant seeding establishment--competition by aggressive herbaceous vegetation for light, soil moisture, and nutrients. Ground vegetation must be properly managed to promote erosion control and soil improvement while minimizing any adverse impacts on tree seedlings. Two herbicides, amitrole and glyphosate, were evaluated for their ability to control herbaceous cover. Glyphosate, applied at 9.50 L/ha, was the more effective of the two in maintaining ground cover density at or below 55%. At this level, seedling survival and growth were significantly improved.

Gilbert, T., T. King, and B. Barnett. 1981. An assessment of wetland habitat establishment at a central Florida phosphate mine site. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-81/38. 96 pp.

This publication reports on a reclaimed mine restoration project initiated in 1978, and carried out by the Florida Game and Fish Commission in cooperation with the International Minerals and Chemical Corporation and the U.S. Fish and Wildlife Service. The 49-acre site, which was mined for phosphate in 1967-68, included both wetland and upland reestablishment areas, and was located in Polk County, FL, adjacent to the Peace River floodplain. In 1978, the area was graded, two water basins were created, and a meandering channel was constructed to connect the basins during periods of high water. Over 10,000 tree seedlings (16t species, including from 9 to 13 bottomland forest species) were planted in 26 test plots. Native herbaceous marsh plants were transplanted to the wetland portion of the site. Plantings, natural plant invasion, hydrology, water quality, and wildlife utilization were evaluated for about 18 months after site construction. The authors concluded that plantings can increase plant species diversity on new sites. Bareroot seedlings, larger transplanted trees, and freshwater marsh plants can be successfully introduced, but species selection and on-site planting location are primary factors to be considered. Natural invasion is also an important factor. The amount of plant subsidy that may be needed is dependent on (1) the distance of individual sites from a natural seed source, (2) the nearby natural plant community type, and (3) dispersal mechanisms. Generally, as the distance from the potential seed source increases, the amount of plant subsidy needed increases. Survival and growth data for each species are presented and reclamation methods are discussed. The authors concluded that although it was not yet possible to assess the long-term ecosystem aspects of wetland reestablishment for the study site, the short-term outlook was promising.

Gilmore, A.R., and W.R. Boggess. 1963. Effects of past agricultural practices on the survival and growth of planted trees. Pages 98-102 in Proceedings of the Soil Sciences Society.

This paper describes the results of a planting of four pine species (loblolly, shortleaf, red, and white) and three hardwood species (sycamore, green ash, and yellow-poplar) on a recently abandoned farm field in southern Illinois. The field had been used for 40 years to test crop rotations with various soil and fertilizer practices; the soil in the field was Wartrace series, which developed from loess. Treatments to portions of the field included the addition of manure, crop residues, limestone, and/or rock phosphate and no treatment controls. Pine seedlings (1-0 for loblolly and shortleaf, and 2-0 for white and red) were machine planted, and hardwood seedlings (all 1-0 stock) were hand-planted in the spring. All pine species survived best on the untreated plots, or on those to which only crop residues had been returned. Survival was significantly less on plots that had been manured, and was drastically reduced on limed plots due to weed competition. Survival of sycamore and yellow-poplar was greatest on plots that had both lime and manure or crop residues. It was concluded that: (1) extreme caution should be used in planting pines on land that has been recently fertilized unless provision is made for weed control; (2) past fertility programs should be investigated; and (3) hardwoods require more fertile sites than pines.

Hansen, N.J., and A.L. McComb. 1955. Growth, form and survival of plantation-grown broadleaf and coniferous trees in southeast Iowa. Proceedings of the Iowa Academy of Science 62:109-124.

This paper summarizes the results of a survey (conducted during 1952-53) of old fields and degraded forest land in southern Iowa, planted with broadleaf and coniferous species during the years 1937-41. Typical bottomland forest species planted included green ash, American elm, cottonwood, and silver maple. Overall, data were collected for 17 broadleaf species and 10 coniferous species. After 12 - 15 years following planting, growth of deciduous species in general was poor on eroded, old-field sites and good on uncultivated and uneroded sites (primarily around abandoned farmsteads). Conclusions were limited because of absence of original planting records and data.

Harris, S.A., H. Bateman, and L. Savage. 1985. Sportsmen's paradise regained. Louisiana Conservationist 37(5):24-25.

This article describes a project to plant Nuttall oak, willow oak, overcup oak, baldcypress, and pecan on approximately 4,500 acres of recently purchased agricultural land. The tract joins the Russell Sage and Ouachita Wildlife Management Areas near Monroe, LA. A 5- to lo-year planting schedule has been planned, with approximately 900 acres/yr to be planted. During the first season, 870 acres of disked fields were planted using 114,000 seedlings and 6,000 lb of acorns. Some of the seedlings were hand-planted; a mechanical planter was used for the acorns. Prior to sowing, acorns were kept in cold storage or underground. As the first year's planting progressed, numerous study plots were established to monitor survival and growth of planted seedlings and acorns. The goal of the project is to reestablish a diverse bottomland hardwood forest on the tract. It is hoped that species such as water hickory, persimmon, elms, willow, sugarberry, and native understory plants will become established through natural regeneration.

Haynes, R.J. 1983. Natural vegetation development on a 43-year-old surface-mined site in Perry County, Illinois. Pages 457-466 in Symposium on surface mining, hydrology, sedimentation and reclamation. University of Kentucky at Lexington.

Natural revegetation was evaluated on a 43-year-old surface-mined site in southern Illinois. For the overstory, 16 species of trees were recorded. When compared with an adjacent oak-hickory climax forest on unmined land, the study site exhibited little similarity, but more closely resembled a southern floodplain or mesic forest type. American elm, cottonwood, sycamore, boxelder, and black cherry accounted for 77% of the importance value. Other volunteer species noted were shingle oak, red oak, pin oak, river birch, willow, hackberry, silver maple, dogwood, sassafras, and persimmon. The rate of succession on the site appeared to be suppressed. The primary factors thought to be limiting succession were competition from dense shrub and herbaceous vegetation and the lack of an available seed source for many heavy-seeded species (e.g., oaks and hickories) at an appropriate time for establishment.

Haynes, R.J., and F. Crabill. 1984. Reestablishment of a forested wetland on phosphate-mined land in central Florida. Pages 51-63 in Proceedings of the fourth annual conference on better reclamation with trees. Purdue University, West Lafayette, IN.

This paper describes the design and implementation of a cooperative forested wetland reestablishment effort involving the U.S. Fish and Wildlife Service, AMAX Chemical Corporation, and various State agencies on a 16-acre (6.5-ha), phosphate-mined site in central Florida (Hillsborough County). The revegetation type (dominant overstory species included red maple, laurel and water oak, and loblolly bay), site preparation, mining activities, grading, topsoil storage, soil amendments, revegetation methods, experimental design, and monitoring are discussed. Study factors included topsoiling; mulching; use of potted plants, bare-root seedlings, and wildlings; natural invasion; control of plant competition; erosion control; establishment of vegetation islands; and evaluation of reclamation success. Data for categorical project costs were also summarized. About 90%-95% of the reclamation cost was estimated to be for earthmoving work involving heavy equipment. Project site revegetation was estimated to account for about 2%-3% of reclamation cost, whereas carrying out the short-term monitoring plan would require from 1% to 2%. Implementation of the revegetation and monitoring plan was scheduled to begin in 1985; thus, data were not available to evaluate the success of the project.

Haynes, R.J., and L. Moore. 1987. Reestablishment of bottomland hardwoods within national wildlife refuges in the southwest. Pages 95-103 in Increasing our Wetland Resources. Proceedings of a conference; National Wildlife Federation-Corporate Conservation Council; Washington, DC.

Increased interest in the protection, conservation, and restoration of bottomland forests prompted the U.S. Fish and Wildlife Service (Southeast Region) in 1987 to review existing examples of bottomland hardwood reestablishment on National Wildlife Refuges in the Southeast. Efforts to reestablish bottomland hardwoods were identified on 12 refuges. Plantings ranged in size from less than 1 ha to about 405 ha and varied in age from about 1 to 19 years after planting. The majority of the planting sites were on periodically flooded land that had been previously farmed. Planting methods included direct seeding of acorns and transplanting seedlings, both of which had distinct advantages and disadvantages. Efforts to control competing vegetation and use of amendments, such as fertilizer, were seldom used. The species most often planted were Nuttall oak, cherrybark oak, willow oak, water oak, and pecan, although several other species were planted. Natural regeneration relative to achieving a diversity of tree species was an important consideration at all sites, and additional evaluation of this issue is needed. Other limiting factors that may affect the success of plantings include (1) drought during the growing season or a late freeze following planting; (2) standing water and high temperature on sites with young seedlings; (3) flooding on sites where the species planted are not adapted either to the duration or the depth of flooding; (4) damage or destruction of seeds or seedlings by rodents, rabbits, or deer; and (5) poor seed viability or poor quality of nursery stock. The small data set evaluated indicated that with attentive management and control of limiting factors, reestablishment of a planned bottomland forest with desired tree species and high value for many species of wildlife should be possible within 40 to 60 years. Additional analysis of other demonstration sites and long-term data sets are needed.

Hosner, J.F. 1957. Effects of water upon the seed germination of bottomland trees. Forest Science 3(1):67-70.

This study was set up to determine the effects of water upon the seed germination of red maple, silver maple, American elm, sycamore, and cottonwood. Samples of 100 apparently sound seeds of each species were randomly selected and split into two lots of 50 seeds each. Half the lots were subjected to soaking in tapwater in a darkened root cellar at approximately 60 °F, for periods varying from 4 to 32 days. The other half were kept dry, but were otherwise subjected to the same treatments. Except for 16 red maple and 2 silver maple seeds, the seeds of elm, sycamore, red, and silver maple did not germinate while soaking in water, but germinated rapidly immediately after removal from water. Germination was consistently high for all periods of soaking. Cottonwood and willow seeds completed their germination in the water after 4 days of soaking and many seedlings were healthy after 32 days of soaking. It was concluded that flooding of bottomland hardwoods for up to 32 days does not seem to have an appreciable effect upon the germination of the six species tested (except possibly through indirect effects of siltation).

Hosner, J.F. 1958. The effects of complete inundation upon seedlings of six bottomland tree species. Ecology 39(2):371-373.

This article discusses the effects of complete inundation of seedlings of six bottomland hardwood tree species--cottonwood, willow, sweetgum, green ash, boxelder, and silver maple--for periods of 2, 4, 8, 16, and 32 days. Except for silver maple, which was grown from seed in a greenhouse, current-year seedlings were collected in the field, transplanted into two-and-a-half inch pots, and allowed to grow for 3 weeks before inundation. The seedlings were about 3 inches high when the test began, and all species except silver maple appeared healthy at the start. Inundation was in tanks placed outdoors in an area exposed to sunlight until 2:00 p.m.; water temperatures during the day ranged from 88-93 °F. The seedlings were kept covered with about a foot of pond water. All species, except silver maple, survived 8 days of complete inundation. After 16 days all replications of willow and green ash survived; two of three replications of sweetgum survived; one of three boxelder survived; no cottonwood survived. After 32 days, only willow survived. Recovery after inundation also varied. Willow and green ash recovered fastest, followed by cottonwood, sweetgum, and boxelder. The species, ranked according to their relative tolerances to complete inundation, were willow, green ash, sweetgum, boxelder, cottonwood, and silver maple.

Hosner, J.F. 1959. Survival, root, and shoot growth of six bottomland tree species following flooding. Journal of Forestry 59:927-928.

The article covers experiments in which green ash, cottonwood, hackberry, sycamore, cherrybark oak, and pin oak seedlings were tested for survival, and root and shoot growth following flooding. Seedlings were immersed for 38 days in enough tapwater to cover the surface of the soil to a depth of about one quarter of an inch, after which they were removed and measured. The four most vigorous appearing seedlings of each species were then kept for another 60 days in moist but well-drained soil, and remeasured. The results showed pronounced differences among the six species in their ability to adjust to changing soil moisture conditions. Cottonwood, sycamore, and ash seedlings rapidly developed adventitious root systems after flooding, but the oaks and hackberry did not. The hackberry seedlings all appeared dead within 3 weeks. The oaks survived, but their roots only weakly recovered after flooding, and no new leaf or shoot growth occurred in the 60-day post-flooding period. Shoot growth recovery was rapid for cottonwood and green ash, but much delayed for sycamore.

Hosner, J.F., and S.G. Boyce. 1962. Tolerance to water saturated soil of various bottomland hardwoods. Forest Science 8(2):180-186.

This study reports on current-year seedlings of 17 bottomland hardwood species native to southern Illinois which were tested for tolerance to water saturated soil. Potted seedlings were subjected to completely saturated soils for 15-, 30-, and 60-day periods by placing pots into tanks filled with tap water to a level of about 1 inch above the soil line. Observations were made on mortality, height growth, development of the established root system, and the formation of adventitious roots. Mortality occurred among seedlings of five species--cherrybark oak, Shumard oak, sugarberry, cottonwood, and American elm. Cherrybark oak was the only species to experience mortality after 15 days, and had the highest mortality after 60 days (86.7%). The tops of all seedlings of the other 12 species were alive after 60 days of complete soil saturation. Nine species actually had faster height growth in soil saturated for 60 days than in unsaturated controls; in order of greatest to least difference, these species were green ash, water tupelo, pumpkin ash, pin oak, willow, sugarberry, cottonwood, silver maple, and boxelder. Species whose height growth was adversely affected were Shumard oak, cherrybark oak, red maple, sycamore, hackberry, sweetgum, willow oak, and elm. The roots of water tupelo, willow, pumpkin ash, and green ash continued to grow under completely saturated soil conditions; the remaining species did not have any actively growing root tips after 30 days, but some (American elm, cottonwood, sycamore, silver maple, and red maple) had many adventitious roots.

Howells, R.G. 1986. Guide to techniques for establishing woody and herbaceous vegetation in the fluctuation zones of Texas reservoirs. Texas Parks and Wildlife Department, Austin, TX.

This publication provides guidance on several aspects of woody and herbaceous plant establishment, including propagule types, collection and storage of propagules, site selection and preparation, planting techniques, protection of plantings, post-planting maintenance, and monitoring. Emphasis is placed on the establishment of selected species which were indentified as suitable for establishment in the fluctuating zones. The woody species selected are willow, cottonwood, buttonbush, swamp privet, sugarberry, baldcypress, and water tupelo. Relevant characteristics of each of these species are described; species are also frequently referred to throughout the chapters on the aspects of establishment.

Hunt, R., J.L. Byford, and J.L. Buckner. 1976. Hardwood regeneration and white-tailed deer compatibility on a large clearcut in an Alabama flood plain. Southlands Experiment Forest Technical Note No. 37. Woodlands Department, Southern Kraft Division, International Paper Company, Bainbridge, GA.

The primary objectives of this study were to determine if large clearcuts in bottomland hardwoods would naturally regenerate with desirable species and if detrimental deer browsing would occur. Two large clearcuts (435 and 490 acres), in an area about 35 mi north of Mobile, AL, were chosen for study. Both clearcuts are subject to annual inundation from overflow of the Mobile River for a 2- to 5-month period during winter and spring. After five growing seasons, both clearcut areas had adequate natural regeneration (1,769 and 1,822 stems/acre). Initial large numbers of deer (about 1/20 acres) did not harm the natural hardwood regeneration. At age 5, cottonwood, sycamore, and green ash dominated the first area; although they composed only 13% of the total number of trees, they ranged from 16-20 ft in average height. Red oaks and sugarberry made up 76% of the trees in the second compartment, and averaged 2-5 ft in height. The differences in regeneration of the two clearcuts were probably the result of different stand histories: the second compartment had been high-graded several years before installation of the study; the first compartment was clearcut in 1968 and the second in 1969; and different amounts of seed were transported to the sites by floodwaters.

Johnson, R.L. 1979. Adequate oak regeneration--a problem without a solution? Pages 59-65 in Management and utilization of oak. Proceedings of the seventh annual hardwood symposium of the Hardwood Research Council; Cashiers, NC.

Two possible solutions to the problem of inadequate oak regeneration in existing southern hardwood stands are discussed: natural and artificial regeneration. The best opportunity for increasing the natural oak component of existing stands is through proper handling of natural oak reproduction. This may involve light thinning or shelterwood cuts and/or removal of competing shade-tolerant mid-story trees. In the section on artificial regeneration, both direct seeding and planting seedlings are discussed. Direct seeding has often been unsuccessful in the past, primarily due to rodent damage. Placing acorns in protective hardware-cloth cylinders has proved to be somewhat effective, but is too expensive to be used much in practice. Studies at Stoneville, MS, show that direct sowing in cleared areas 3 acres or larger results in much less rodent damage than smaller openings or underplanting acorns in forests. Planted seedlings, with weed control by straddle-cultivation and disking, resulted in several successful oak plots ranging from 20 to 200 acres. Best results were obtained with seedlings greater than 24 inches tall and at least 0.3 inches at the root collar. Planted oaks generally averaged a foot or two in annual height growth for the first 1 or 2 years in the field, and increased to 3 or 4 ft/year in the third and fourth years of growth. Care must be taken when planting old fields or cleared sites where desired oak species are absent. Also, in some cases soil pH can be a critical consideration. For example, an experimental planting of Nuttall, cherrybark, and water oaks failed on a moist, fertile bottomland soil with a relatively high pH (7.5), presumably because the seedlings were unable to extract iron from the soil. Experience indicates that oaks normally found in areas inundated for extended periods can be successfully planted on higher, better-drained sites, but the opposite is not true.

Johnson, R.L. 1981a. Oak seeding - it can work. Southern Journal of Applied Forestry 5(1):28-33.

The article describes a direct-seeding trial in which nearly 20,000 acorns of Nuttall oak were sown in Sharkey clay soil in the Delta Experimental Forest near Stoneville, MS, to compare field germination of acorns at different presowing treatments, different sowing times, and different sowing depths. Acorns were collected in November 1968 from 14 parent trees and were placed in dry storage at 35-40 °F. Float tests were used to eliminate unsound acorns, and sound acorns were randomly assigned one of three stratification treatments: January sowing in the field; 3 months additional storage at 35-40 °F in moist sand covered with burlap; or 3 months additional storage at 35-40 °F in sealed polyethylene bags, 4-mils thick. Acorns stratified in these three treatments were then planted at 1-, 2-, and 4-inch sowing depths. Acorns in the second two stratification methods were sown during the first 2 weeks of May 1969 at a spacing of 5 by 10 ft with 4 acorns planted in each spot. Rodents destroyed all acorns planted in undisturbed forest sites within a week, and damaged nearly three-fourths of the acorns sown in 40 by 90 ft cleared strips. Sowing in these two areas was considered a failure and not monitored further. Less than 5% of the acorns sown in 350 by 350 ft cleared plots were disturbed by rodents. Acorns sown 1 inch deep in January germinated significantly better (55% of total sown) than any of the other eight combinations of stratification treatments and sowing depths.

Johnson, R.L. 1981b. Wetland silvicultural systems. Pages 63-79 in Proceedings of the thirtieth annual forestry symposium, Louisiana State University, Baton Rouge.

Silvicultural systems are discussed that are applicable to one or more species groups occurring on lowland sites in the Midsouth. The species groups are cottonwood, elm, sycamore, pecan, sugarberry, sweetgum, water oaks, red oaks, white oaks, mixed species; black willow; overcup oak, water hickory; elm-ash-sugarberry; and cypress-water tupelo. Each of these species groups is related to the type of physiographic site on which it is generally found. Cottonwood, black willow, overcup oak-water hickory, and cypress-water tupelo are best managed as even-aged species groups, while the other groups can be managed as even-aged or uneven-aged stands. Five regeneration systems are recognized for lowland hardwood forests and are briefly discussed, including single tree selection, group selection, seed tree, shelterwood, and clearcuts. A table summarizes the expected results of applying some of these generation systems to the species groups.

Johnson, R.L. 1983. Nuttall oak direct seedings still successful after 11 years. U.S. Forest Service Research Note SO-301, New Orleans, LA. 3 pp.

This technical note reports on a successful Nuttall oak direct-seeding experiment on a Sharkey clay site in the Delta Experimental Forest, near Stoneville, MS. Forty-five hundred acorns were sown on an intensively-prepared site in April, 1971. Sowing treatments included hand-planting and machine planting at depths of 2, 4, and 6 inches. The first seedlings appeared in early May from acorns sown 2-inches deep; seedlings from 6-inch-deep acorns appeared about 2 weeks later. Some earlier direct-seeding trials had failed due to rodent depredation of acorns, but in this case, less than 10% of the acorns were believed to have been destoyed by rodents. Field germination ranged from 27% to 41%; better germination was obtained with hand sowing (versus machine) and 2-inch (versus deeper) sowing depths. Overall, 96% of the seedlings alive after one growing season were still alive after 11 years, and no significant difference in survival existed among treatments. The largest Nuttall oaks were 3-4 inches dbh and 20-25 ft tall. About one-third of the 11-year-old trees were overtopped partially or completely. Naturally invading tree species were green ash, cottonwood, sugarberry, sweetgum, American elm, persimmon, and water hickory. Except for two 6-inch-dbh, 35-foot-tall cottonwoods, however, the largest non-oaks were about the same size as the largest Nuttalls.

Johnson, R.L., and R.C. Biesterfeldt. 1970. Forestation of hardwoods. Forest Farmer November: 15, 36-38.

Forestation of hardwoods by both natural regeneration and planting is discussed. In general, successful plantations of hardwoods depend on the forester's ability to choose the proper sites, species, and tree spacings. Sites usually cannot be easily modified to suit a particular species. Green ash, sweetgum, Nuttall and willow oak, sycamore, and cottonwood are generally suitable for slackwater sites. In areas where water stands for much of the growing season, green ash or Nuttall oak should be planted; in slightly drier areas, cottonwood and sycamore are recommended because of their rapid growth. Spacing is the least important of the three initial choices, but becomes more important as the stand develops. A key consideration when deciding on spacing is the amount of weed control planned. If little or no weed control is planned, spacing should be as close as practical (no more than 6 by 6 ft); spacing should be 12 by 12 ft or wider if complete weed control is exercised. Weed control is especially critical in cottonwood plantations, but produces better results in all species. Weed control ideally should be carried out until the tree crowns close and shade-out competition. Based on the limited data available, projections of tree size at age 10 for suitable sites are cottonwood, 60-80 ft in height and 6-8 inches dbh; sweetgum, 20-30 ft in height and 2-3 inches dbh; and yellow-poplar and sycamore, 50-60 ft tall and 5-6 inches dbh.

Johnson, R.L., and R.M. Krinard. 1985a. Oak seeding on an adverse site. U.S. Forest Service Research Note SO-319, 4 pp.

The study reports on Nuttall and water oak acorns sown on an old-field site of Sharkey clay soil near Greenville, MS. The field had been farmed for 15-20 years, and was typical of many marginal crop production sites in the region. Acorns were collected from three Nuttall and three water oaks; the parent trees were selected because they produced different-sized acorns. Acorns were float-tested, and non-floaters were stored at 35 to 40 °F for about 3 months in polyethylene bags. Treatments were combinations of parent trees (i.e. different acorn sizes) and sowing depths (2, 4, and 6 inches). Acorns were hand-sown on a 4 by 10 ft spacing, with three acorns planted per hole. Twice during the first year, the strips between each row were mowed. Seedling survival after one growing season was 55% for Nuttall oak and 35% for water oak. Large water oak acorns did very poorly; if they are excluded, average seedling survival was 49%. Over 90% of Nuttall oak acorns germinated by late July; most water oak acorns germinated in August and September. Sowing depth of both species affected germination, which declined with depth; the best germination depth was 2 inches. By the end of the first growing season, the tallest seedling per spot averaged 0.56 ft for Nuttall oak and 0.26 ft for water oak.

Johnson, R.L., and R.M. Krinard. 1985b. Regeneration of oaks by direct seeding. Pages 56-65 in Proceedings of the third symposium of southeastern hardwoods, Dothan, AL. U.S. Forest Service Southern Forest Experiment Station, New Orleans, LA.

Results of oak seeding research at Stoneville, MS, and a number of commercial seedings are given. Research sites included eight in the Mississippi Delta, two in minor stream bottoms, and'five in silty uplands. Commercial sites were in the Mississippi Delta and silty uplands. Topics covered included animal damage, species, site selection, seed collection and storage, time of seeding, depth of seeding, method of sowing, spacing, weed control, survival and growth, and the future of oak seeding. It was found that site-prepared clearings of two acres or more and old agricultural fields have less rodent damage than smaller clearings or plantings under a full forest canopy. Nuttall oak has consistently yielded the best results of the species tried to date, and, in general, red oaks germinated better in the field than white oaks. Timing and duration of flooding and soil type are key considerations in site selection. Seed should be collected soon after falling and placed in cold storage immediately. Acorns can be sown at any time of year, but June or July is best in flood-prone areas after the water has receded. Trials have been conducted with three planting depths: 2, 4, and 6 inches; all can be successful, but a P-inch depth generallv yields the best results. Spacing can vary, but should leave about 30 ft^2/acorn. Intensive weed control by disking has been shown to improve early height and diameter growth.

Johnson, R.L., and R.M Krinard. 1987. Direct seeding of southern oaks--a progress report. Pages 10-16 in Proceedings of the fifteenth annual hardwood symposium. Hardwood Research Council, Memphis, TN.

This paper summarizes some of the experience gained since 1981 in the direct seeding of over 4,000 acres of land in the South. Most of these plantings have been on abandoned farm lands in floodplains. The report includes information on associated costs, seed handling, planting methods, survival, growth, and competition. Sowing in the winter generally produces the best results, although satisfactory results have also been obtained from summer plantings, and, in the case of Nuttall oak, from plantings done every month of the year. One possible advantage of sowing in winter is that acorns sown soon after collection (which is done in fall) seem to be damaged less by rodents. Although it is best to plant acorns as soon after collection as possible, the irregular occurrence of good seed crops may necessitate storing extra acorns in good years to offset future bad years. The cost of collecting acorns was estimated at $20.00/acre, and of storage, $0.50-$2.00/acre. Planting in large open fields has generally been done using modified soybean planters. Planting is easier and produces better results when the site has been well prepared. Burning, disking or cross-disking, and soil pulverizing may be necessary, depending on the condition of the field. Smaller fields or openings in forests have been successfully planted by hand. Most land managers do not attempt to control weeds in old field plantings, but in a few research trials, bushhogging between rows appears to have improved seedling survival and growth. Total costs of establishment by direct seeding, including acorns, labor, and site preparation, may range from $12.00-50.00/acre. The paper concludes with a section on direct-seeding failure, which has been attributed to flooding, droughts, residual herbicides, poor quality acorns, and animal damage.

Johnson, R.L., and T.L. Price. 1959. Resume of 20 years of hardwood management on the Delta Purchase Unit. Final Report. U.S. Forest Service Southern Forest Experiment Station, New Orleans, LA.

Hardwood research on the Delta Purchase Unit, located near Rolling Fork, MS, is summarized. The report begins with a detailed description of the Unit, including physiographic features, occurrence of wildfires and floods, climatic conditions, vegetative features, and natural areas. Discussion of the forest management and research program is divided into four sections: (1) fire, (2) cutting program, (3) cull-and-weed tree deadening, and (4) planting. In 1945-58, there were 35 different attempts at planting, totaling approximately 700,000 trees. Green ash, sweetgum, cottonwood, baldcypress, Nuttall oak, and sycamore were planted. Most of the planting stock was 1-0 seedlings grown from locally collected seed, but cottonwood was the major exception; cuttings were used for this species. In a few cases, transplanted wild seedlings (wildlings) were used. Most planting was done during February and March, and planting was done by hand under three conditions: (1) areas infested with heavy buckvine; (2) stand openings created by logging; and (3) stand conversion areas. Overall, 80% of the green ash, 73% of the baldcypress, 41% of the cottonwood, and 10% of the sweetgum plantings were judged successful. All sycamore, Nuttall oak seedlings and wildlings, and green ash plantings were failures. Based on average growth of all plantations, cottonwood grew 3.0 ft/year, green ash 1.5 ft, and baldcypress and sweetgum, 1.2 ft. The paper discusses in detail species results by physiographic site and the three planting site conditions mentioned above.

Jones, L. 1962. Recommendations for successful storage of tree seed. U.S. Forest Service Tree Planters' Notes 55:9-20.

This article provides recommendations on moisture content, temperature and other seed storage considerations for a large number of species and species groups, including most bottomland hardwoods. In storing tree seed the following must be considered: type of container, seed moisture content, storage temperature and facilities, and seed condition. Several studies have shown that seed moisture content rises during closed storage, and it is suggested that seed should be dried down to the lowest recommended level and moisture content checked periodically, especially if the seed is to be stored longer than 1 year. Storage temperature should be held constant. Some species, such as oaks, will benefit from treatment for insects prior to storage, otherwise insects may become active again immediately upon removal of the seeds from storage.

Kaszkurewicz, A., and P.Y. Burns. 1960. Growth of planted hardwoods on a bottomland terrace site in south Louisiana. Louisiana State University Forestry Note No. 37. Louisiana State University, Baton Rouge. 2 pp.

Growth of a 30-year-old plantation of Nuttall oak, water oak, live oak, swamp chestnut oak, and yellow-poplar is described. The plantation is located on the Louisiana State University campus in Baton Rouge, and is described as follows: a Mississippi River terrace (not subject to flooding); mean annual temperature, 68 °F; average annual rainfall, 59 inches; soil, Lintonia silt loam (well-drained, 1%-2% slope, pH 5.8). The site was a former agricultural field that was covered with weeds and brush when the trees were planted. Planting was done by hand with 1-0 stock at about 10 by 10 ft spacing. About 5 years after planting, the trees were released from weed and brush competition. After 30 years, except for Nuttall oak, the trees were generally healthy. Nuttall oak is not native to the site, which may be too dry; most of the Nuttall oaks had dying branches and tops, rough bark with insect holes, and a marked decrease in diameter growth during the last 5 years. Yellow-poplar had the greatest average diameter growth (14.7 inches) and height growth (82 ft). Nuttall oak dbh and height averaged 11.9 inches and 72 ft. Corresponding figures for the other species were water oak, 11.7 inches and 75 ft; live oak, 10.2 inches and 66 ft; and swamp chestnut oak, 8.5 inches and 72 ft. Sweetgum was a significant invader species, averaging 9.6 inches in dbh and 75 ft in height.

Kellison, R.C., D.J. Frederick, and W.E. Gardner. 1981. A guide for regenerating and managing natural stands of southern hardwoods. North Carolina Agricultural Research Service Bulletin 463. 23 pp.

This bulletin is primarily a guide for obtaining good natural regeneration from existing stands of southern hardwoods, but it contains some information that may aid in species selection for unforested sites and management of young stands. The guide has four major sections: (1) planning for regeneration; (2) regeneration systems; (3) species succession and stand development; and (4) species composition and stocking control. Natural regeneration topics briefly discussed are stand conditions, site types, when to regenerate, response of species to release, and growth habits of seedling and coppice regeneration. Regeneration systems covered are single-tree selection, group selection, shelterwood, tree, and clearcut. A description of naturally-occurring succession on various site types and shade-tolerant undesired species is given. The last section discusses management of 1- to 25-year-old stands from an economically oriented timber production perspective.

Kennedy, H.E., Jr. 1984. Hardwood growth and foliar nutrient concentrations best in clean cultivation treatments. Forest Ecology and Management 8:117-126.

This article presents data on nine hardwood species planted on a 4-ha commerce silt loam site at Huntington Point, about 24 km north of Greenville, MS. The site had been recently cleared of a natural mixed hardwood stand and prepared for planting by shearing, root raking, and disking. Twenty-four 1-year-old seedlings or cottonwood cuttings were planted in February at 3 by 3 m spacing in each plot. The species planted were cottonwood, sycamore, Nuttall oak, cherrybark oak, water oak, pecan, green ash, sweetgum, and yellow-poplar. One of three cultural treatments--no cultivation, mowing, or clean cultivation (cross-disking plus hoeing)--was randomly assigned to a plot. Growth and survival of yellow-poplar was excellent during the first growing season, but all the seedlings were killed during the second season when the site was flooded to a depth of 1.8 m from late March to late May. None of the other species was harmed by the flood. Nuttall, cherrybark, and water oak had poor survival and growth, which was probably due to the high soil pH (8.0). Survival and height and diameter growth were significantly higher in the clean cultivated plots. After 4 years, height and diameter growth were highest for cottonwood, followed by sycamore, green ash, sweetgum, and pecan. Average survival was 8% (excluding the oaks and yellow-poplar) for the clean cultivated plots, 65% for mowed plots, and 61% for uncultivated plots.

Kennedy, H.E., Jr., and R.M. Krinard. 1974. 1973 Mississippi River flood's impact on natural hardwood forests and plantations. U.S. Forest Service Research Note SO-177. 6 pp.

The impacts of the 1973 Mississippi River spring flood (6-11 ft maximum depth) on bottomland hardwood species are described. Most of the damage was to planted and natural bottomland hardwood stands less than 1 year old. Species suffering heavy mortality included cottonwood, sweetgum, yellow-poplar, and Shumard oak; sycamore and green ash plantings showed good survival. All yellow-poplar of all ages were killed. Trees of other species that were older than 1 year suffered some damage but were generally able to survive the flood. There were some indications that seedlings survived better than planted cuttings. The length of time of inundation seemed to be a factor in overall tree survival. Nuttall oak acorns that were direct-seeded the year before survived the flood. Siltation of up to 5 ft occurred, but did not adversely affect well established trees. Oxygen levels in the flood waters were generally adequate and did not appear to be a prime cause of mortality.

Kennedy, H.E., Jr., and R.M. Krinard. 1985. Shumard oaks successfully planted on high pH soils. U.S. Forest Service Research Note SO-321, New Orleans, LA. 3 pp.

This paper reveals that many Mississippi riverfront soils are devoid of oak forests, and planting trials with Nuttall, cherrybark, and water oaks have not been successful on such soils. One reason may be the high pH of many riverfront sites, which may range from 7.5 to 8.0. Three trials with Shumard oak, however, have proved successful. Shumard oak was planted in 1959 at Archer Island in Washington County, MS, on Robinsonville sandy loam, and at Huntington Point in Bolivar County, MS, in 1974 and 1975 on Commerce silt loams. Nursery-grown, 1-0 bareroot seedlings were planted at 10 by 10 ft spacings on sites that were cleared of a natural stand of mixed hardwoods and prepared by shearing, root raking, and disking. Plantings were clean cultivated during the first growing season, but no intensive weed control was applied afterwards. After both 12 and 25 growing seasons, survival averaged 86% at Archer Island. Survival at Huntington Point was 73% after 10 growing seasons at one site and 80% after 11 growing seasons at the other site. Diameter growth averaged 0.5 inch/year for all three plantings, while height growth averaged 3.0 to 4.0 ft/year. In another study, Nuttall, water, and cherrybark oaks were planted within 200 ft of one of the Shumard oak plantings at Huntington Point. The leaves of the former three species turned yellow early in each growing season, and the trees grew very little. After four growing seasons, survival was only 10%-40%.

Kennedy, H.E., Jr., B.E. Schlaegel, and R.M. Krinard. 1986. Nutrient distribution and tree development through age 8 of four oaks planted at five spacings in a minor stream bottom. Pages 65-70 *in* Proceedings of the 1986 southern forest biomass workshop, Knoxville, TN.

This paper reports on the results of experiments with eight hardwood species planted at five spacings in a minor stream bottom in southeastern Arkansas, about 10 mi south of Monticello. The species planted were water, Nuttall, cherrybark, and swamp chestnut oaks, sycamore, sweetgum, cottonwood, and green ash; however, only data from the oaks were presented in the paper. The soil series was Arkabutla, a somewhat poorly drained silty alluvium. Spacings used were 2 by

8, 3 by 8, 4 by 8, and 12 by 12 ft; the minimum of 8 ft between rows was chosen to allow cultivation during the first growing season. Data are presented on total dry weight of trees (without leaves) per acre, cubic feet of wood per acre, leaf weights per acre, survival, dbh, and height after eight growing seasons. Spacing significantly affected all variables, except survival and height, and all variables except survival were different for the various species. Survival for all oak species ranged from 75% for 8 by 8 ft spacing, to 83% for 4 by 8 and 12 by 12 ft spacing. Water oak had the largest average dbh (2.2 inches) and the largest average height (20.1 ft), followed by Nuttall oak (2.1 inches and 16.7 ft), cherrybark oak (1.8 inches and 15.8 ft), and swamp chestnut oak (1.3 inches and 11.0 ft). Yields (by weight and volume) were larger with small spacings, though yields per tree were lower.

Klawitter, R.A. 1963. Sweetgum, swamp tupelo, and water tupelo sites in a South Carolina bottomland forest. Ph.D. Dissertation. Duke University, Durham, NC.

Sweetgum, swamp tupelo, and water tupelo habitats were studied in a coastal plain bottomland forest adjacent to the Santee River in South Carolina. Site variables evaluated included elevation, hydrology, woody understory vegetation, and soil characteristics. Results showed that sweetgum sites were better drained, with a higher pH, than tupelo sites. Water tupelo soils exhibited greater clay content and depth of flooding; swamp tupelo soils showed lowest pH. Abundant soil moisture and long hydroperiods were positively related to growth of water tupelo. Laurel oak in the understory was associated with well-drained sites at the lower margins of first bottoms. Green ash preferred swampy sites that remained wet for long periods without deep flooding. American elm occurred mostly along the upper slopes of the swamp and lower edges of the first bottom. Carolina ash, red maple, and green ash decreased in abundance with the increased height of water tupelo.

Krinard, R.M., and R.L. Johnson. 1976. El-year growth and development of bald cypress planted on a flood-prone site. U.S. Forest Service Research Note SO-217, New Orleans, LA. 4 pp.

Results are given of a study in which a total of 896 one-year-old cypress seedlings were planted on a Sharkey clay site in the Delta Experimental Forest in Washington County, MS, in February 1955. The site was about 20% ridge, 20% slough, and 60% flat-slough, with a 3-ft difference in elevation between the flat and the slough. About l-2 ft of water covered the slough in winter. The site flooded frequently, and three earlier attempts to plant cottonwoods in the area failed due to excessive flooding and heavy competition from vines. Survival after 21 years was 41%, but some of the cypress were suppressed and were not expected to survive much longer. Invading species noted were green ash, boxelder, sugarberry, persimmon, blackwillow, and cottonwood, which collectively accounted for about 26% of the total density. Density of cypress was about 74%.

Krinard, R.M., and R.L. Johnson. 1981. Flooding, beavers and hardwood seedling survival. U.S. Forest Service Research Note SO-270, New Orleans, LA. 6 pp.

Trial plantings made for three successive years on cleared, clay-capped batture land at Ajax Bar in Issaquena County, MS, are discussed. Seven species were planted, including cottonwood, sycamore, green ash, sugarberry, swamp chestnut oak, Shumard oak, and pecan. In the first year there was no flooding, but during the second year flooding occurred for varying periods from late winter through early summer. No beaver damage was noted when there was no flooding, but during the flooded periods, significant damage to all species (with the possible exception of sycamore) was observed. The beavers apparently damaged the seedlings while they were in shallow water, pulling the seedlings out of the ground and eating the root system up to about the root collar. Consecutive long rows of damaged trees were observed. Up to 43% of the seedlings of some species were destroyed. Shumard oak was hurt most by the floods, and green ash and sycamore fared best. Green ash and sycamore are recommended for planting if substantial first-year flooding is likely.

Krinard, R.M., and H.E. Kennedy, Jr. 1981. Growth and yields of 5-year-old planted hardwoods on Sharkey clay soil. U.S. Forest Service Research Note SO-271, New Orleans, LA. 3 pp.

Cottonwood, sycamore, green ash, sweetgum, and Nuttall oak seedlings were planted on a Sharkey clay site. The seedlings were planted on a 10 by 10 ft spacing, and the plots were cross-disked or mowed three to five times a year for six growing seasons. Before the sixth season, height and diameter of all trees were measured, and a total of 12 trees of each species were felled and weighed. Mowed plots of sweetgum and Nuttall oak were not considered because survival was less than or equal to 50%. Survival on the other plots ranged from 81% for mowed cottonwood to 99% for disked sycamore. Whether mowed or disked, sycamore and green ash had 95% or better survival. Mean dbh and height ranged from 4.0 inches and 25.8 ft for disked cottonwood to 1.0 inch and 8.6 ft for disked Nuttall oak. Disked plots consistently had higher survival and better diameter and height growth than mowed plots.

Krinard, R.M., and H.E. Kennedy, Jr. 1983. Ten-year growth of five planted hardwood species with mechanical weed control on Sharkey clay soil. U.S. Forest Service Research Note SO-303, New Orleans, LA. 4 pp.

Studies on mechanical weed control are reported for five species of southern hardwoods (cottonwood, sycamore, green ash, sweetgum, and Nuttall oak) that were planted on a Sharkey clay site on the Delta Experimental Forest, near Stoneville, MS. Plots, consisting of 24 trees of one species planted on a 10 by 10 ft spacing, were mowed or disked from three to five times annually for the first 5 years. After the fifth year, plots with 80% or more survival for trees more than 4.5 ft tall were thinned to six trees each, or an equivalent of 20 by 20 ft spacing. Mowing or disking treatments, one to three times annually, for years 6-10 were randomly assigned. Some plots were mowed or disked each year for 10 years; some plots were mowed the first 5 years and disked years 6-10, and some were disked the first 5 years and mowed years 6-10. Disking resulted in better growth of all species over the first 5 years, but for years 6-10, there was only a slight difference in height, dbh, or volume between treatments. Overall height growth through 10 years was from 1.7 to 4.9 ft/year, depending on species-treatment combination. Cottonwood was the tallest species overall after 10 years, followed by sycamore, green ash, sweetgum, and Nuttall oak. Soil moisture was not significantly different between treatments, and after 10 years there was no significant difference in soil properties (pH, organic matter, N, P, K, Ca, and Mg) between treatments.

Krinard, R.M., and H.E. Kennedy, Jr. 1987. Fifteen-year growth of six planted hardwood species on Sharkey clay soil. U.S. Forest Service Research Note SO-336, New Orleans, LA. 4 pp.

This article discusses further results (see Krinard and Kennedy 1983) of mowing and disking experiments on six hardwood species (cottonwood, sycamore, green ash, sweetgum, Nuttall oak, and pecan) which were planted on a Sharkey clay site on the Delta Experimental Forest, near Stoneville, MS. Mowing or disking treatments for years 6 through 10 were found to have little effect on growth; therefore, results are discussed relative to the first 5 years of weed control treatments. At age 15, trees on plots disked the first 5 years were significantly taller and larger in dbh than trees on mowed plots, but overall the differences were only 1.3 ft in height and 0.6 inches in dbh. The relatively small differences after age 15 imply different growth patterns for trees in disked versus mowed plots. One possible explanation is that mowing, which results in higher competition initially, may cause tree roots to grow deeper where extra nutrients and water may speed growth in later years. Average dbh and height after 15 years on the disked plots were: cottonwood, 11.0 inches and 60.4 ft; sycamore, 6.5 inches and 37.7 ft; green ash, 6.5 inches and 36.3 ft; sweetgum, 5.9 inches and 30.6 ft; Nuttall oak, 5.8 inches and 20.2 ft; and pecan, 3.4 inches and 21.7 ft.

Larsen, H.S. 1963. Effects of soaking in water on acorn germination of four southern oaks. Forest Science 9(2):236-241.

Southern red oak, willow oak, laurel oak, and overcup oak were tested to determine whether flooding is instrumental in controlling the distribution of some southern oaks by differential effects on acorn germination. Two soaking variables were tested: length of soaking and water temperature. Soaking periods were 1, 2, 4, and 8 weeks. Two temperature levels were imposed--the first a controlled range of 44.0-46.6 °F, and the second an unregulated diurnally fluctuating range of 55-64 °F. Lots of 50 acorns each were subjected to each time/temperature treatment, with unsoaked lots of each species serving as controls. After soaking, all seed lots were sown simultaneously in moist sand at a depth of 1/2 to 3/4 inches, and kept at a soil temperature of 73-81 °F. The results did not support the hypothesis that injury to acorns by flooding is a primary reason for exclusion of dry-site species from bottomland sites. Average germination for all soaking treatments for southern red oak (the driest-site species tested) was 87%, compared to 92% for unsoaked acorns. The minimum germination observed was 66% for laurel oak soaked for 2 weeks, compared to 77% for the control. Overcup oak had the lowest overall germination (82%), but showed improvement in a second test when the acorn shells were opened prior to soaking.

Leitman, H.M., J.E. Sohm, and M.A. Franklin. 1983. Wetland hydrology and tree distribution of the Apalachicola River flood plain, Florida. U.S. Geological Survey Water Supply Paper 2196, Alexandria, VA. 52 pp.

This assessment focuses on hydrology and productivity of the floodplain forest associated with the Apalachicola River in northwest Florida. Forest types were found to be highly correlated with depth of water, duration of inundation and saturation, and water-level fluctuation, but not water velocity. Most types dominated by tupelo and baldcypress grew on permanently saturated soils inundated 50%-90% of the time (an average of 75-225 consecutive days during the growing seasons from 1958-80). Most forest types dominated by other species grew in areas saturated or flooded 5%-25% of the time (an average of 5-40 consecutive days during the growing seasons from 1958-80). Average basal area and density for all forest areas sampled were 46.2 m^2/ha and 1,540 trees/ha, respectively. The relative tolerance of bottomland tree species to inundation is discussed.

Limstrom, G.A. 1960. Forestation of strip-mined land in the central states. U.S. Forest Service Central States Forest Experiment Station Agricultural Handbook No. 166, Washington, DC. 74 pp.

The publication is an excellent technical guidebook based on research studies beginning in 1937. The author notes that commonly accepted reforestation practices are not always successful because strip-mine spoil banks are so different from most natural planting sites physically, chemically, and biologically. Emphasis is placed on the where, when, and how of tree planting on mined lands as related to existing mining and reclamation methods. The report includes recommendations and discussions of the effects of various site conditions and planting methods. Several typical bottomland forest species are included in the data and discussion, including green ash, eastern cottonwood, silver maple, and sycamore. Also discussed are the detrimental effects of grading on soil moisture and aeration, and the ecology of natural forestation.

Limstrom, G.A. 1963. Forest planting practice in the central States. U.S. Forest Service Central States Forest Experiment Station Agricultural Handbook 247, Washington, DC. 69 pp.

This handbook provides useful guidance on a number of topics including species selection for various sites, site preparation, where to obtain trees, quality and care of planting stock, planting methods and patterns, care and management of plantations, forest pests and diseases, how to make planting plans, and treatment of seeds. The States included are Illinois, Indiana, Iowa, Kentucky, Missouri, and Ohio.

Lotti, T. 1959. Selecting sound acorns for planting bottomland hardwood sites. Journal of Forestry 57:923.

The article discusses methods of determining the viablity of acorns to be used for planting hardwoods. Nut or acorn weevils seriously limit the viability of acorns. Flotation in water is a commonly accepted method of separating weeviled from sound acorns before planting; sound acorns usually sink. The soundness of Shumard oak and cherrybark oak acorns, however, can be judged with certainty by the color of the basal or cup scar. If the circular scar is a light tan, the acorn is sound; if a dull brown, the acorn is defective. These color relationships are easily established in actual practice. Since Shumard and cherrybark are red oaks, this method may have a broader application to the red oak group. The method does not work well, however, with swamp chestnut oak, which belongs to the white oak group. The success of the visual selection, as evidenced by high germination percentages, makes further weevil treatment unnecessary.

Loucks, W.L., and R.A. Keen. 1973. Submersion tolerance of selected seedling trees. Journal of Forestry 71:496-497.

This Kansas study helps to identify seedlings which have high submersion tolerance. Seedlings of 10 species were covered with 2 ft of water for periods of 1, 2, 3, and 4 weeks to test submersion tolerance. The seedlings were planted in five flat-bottom ponds constructed near Manhattan, KS, in an area of Wymore silty clay loam soil. Four of the ponds were filled with well water and one was left unflooded as a control. Species planted were green ash, baldcypress, silver maple, pecan, cottonwood, honeylocust, bur oak, boxelder, Siberian elm, and black walnut. There was no significant mortality in any species in the 1- and 2-week submersion treatments. In the 3-week treatment, survival was still 100% for green ash, baldcypress, cottonwood, and silver maple, but dropped to between 44% and 67% for the remaining species. Survival after 4 weeks ranged from zero for black walnut to 100% for green ash and baldcypress. The remaining species in order of survival from highest to lowest were silver maple, pecan, cottonwood, honeylocust, bur oak, boxelder, and Siberian elm.

Maisenhelder, L.C., and C.A. Heavrin. 1957. Silvics and silviculture of the pioneer hardwoods--cottonwood and willow. Pages 73-75 in Proceedings of the 1956 annual meeting of the Society of American Foresters.

The authors cover five topics related to the silvics and silviculture of cottonwood and willow in the lower Mississippi Valley: (1) site development, (2) seedling establishment, (3) establishment and growth, (4) natural enemies, and (5) artificial regeneration. The site development section describes the formation of new land on "point bars" in the river, where cottonwood and willow typically are found. The next two sections describe the natural establishment and growth of cottonwood and willow on these new lands. Natural enemies discussed in the fourth section include fire (both cottonwood and willow are very susceptible); sustained submergence of young trees during the growing season; cattle, hog, and deer browsing; and defoliating insects, especially on cottonwood. The final section briefly describes propagation and plantation establishment from cuttings, which is especially suitable for clearcut areas and old agricultural fields. It is recommended that cuttings be taken from 1- to 3-year-old seedlings or sprouts; individual cuttings should be about 20 inches long and from 3/8 to 3/4 inches diameter at the small end. The cuttings should be placed 15 inches into the ground; planting into a slit made by a sub-soil plow is preferable to using a planting bar if tree roots are not a problem. Spacing of about 10 by 10 ft is desirable to allow for weed control. Weeds should not be allowed to exceed three-fourths of the height of the seedlings during the first growing season. On good sites under favorable conditions, first year survivals of 75%-90% may be expected, with an average height growth of about 5 ft. Growth of 10 ft in height and 1 inch in dbh have been attained.

Maki, T.E., A.J. Weber, D.W. Hazel, S.C. Hunter, B.T. Hyberg, D.M. Flinchum, J.P. Lollis, J.B. Rognstad, and J.D. Gregory. 1980. Effects of stream channelization on bottomland and swamp forest ecosystems. University of North Carolina, Water Resources Research Institute, Raleigh.

This study evaluates the effects of stream channelization on the bottomland-swamp forest ecosystems of eastern North Carolina. Groundwater regimes in the floodplains were monitored to provide a basis to compare plant communities. Aboveground biomass of shrub and herbaceous vegetation was found to be inversely related to the number of inundation periods per year. Competition from this "lesser vegetation" was deleterious to planted and naturally regenerated tree seedlings along the channelized streams. Regeneration of water tupelo, swamp blackgum, and baldcypress appeared to have been reduced in channelized areas; these species were particularly sensitive to competition from overstory vegetation and the profusion of vines, grasses, and briars associated with the decrease of groundwater levels in channelized swamps. Survival and growth of planted tupelo seedlings were greater along non-channelized streams than along channelized streams; the latter seedlings were adversely affected by fierce competition from honeysuckle and blackberry canes. Regeneration in cutover areas was sometimes less than in non-cut areas because the cutover areas exhibited an increase in vines, briars, and other woody reproduction which precluded the reestablishment of trees. This situation could persist for an indefinite period of time unless flooding or some other factors reduce competition. For comparison, the authors reported on a well-managed swamp forest stand along the Roanoke River at Tillery, Halifax County, NC, that originated from a clearcut of a tupelo tract about 70 years earlier. With little or no overstory competition, water tupelo and some baldcypress became established and grew well. After about 70 years, the Tillery stand contained a standing volume of about 1,000 m^3/ha in non-cut areas and from 350 to 625 m^3/ha in areas thinned in 1962.

Malac, B.F., and R.D. Heeren. 1979. Hardwood plantation management. Southern Journal of Applied Forestry 3(1):3-6.

In this paper, some of the hardwood silvicultural practices of Union Camp Corporation are detailed. These practices are based on 10 years of hardwood plantation research carried out near Franklin, VA, and include seed collection, site selection, planting stock, site clearing, site preparation, planting, spacing, competition control, fertilization, harvesting, and coppicing. Species planted include sycamore, green ash, sweetgum, and willow, water, and laurel oaks. All seed is collected from the best available local trees, but the company is in the process of developing clonal seed orchards. Sites chosen for planting hardwoods have a sandy loam or loam surface fairly high in organic matter, are moderately well-drained, and have a water table to within 4 inches of the surface during portions of the year. Only large, healthy seedlings, with a minimum root collar diameter of 3/8 inch and a top height of at least 2 ft are planted. All sites are intensively cleared, except for recently abandoned agricultural land. Some sites are disked prior to planting, abandoned fields with plow pans or shallow topsoil are subsoiled, and wet sites are bedded. Seedlings are planted with tractor-drawn machine planters modified to handle large seedlings. Sycamore and the oaks are planted on a 10 by 10 ft spacing and green ash and sweetgum on a 8 by 12 ft spacing. Depending on site and weed growth, plantations are disked on the average of two to three times a year for at least the first 2 years. As a rule, fertilizer is applied during the first cultivation; applications vary, but often about 250 lb/acre of triple superphosphate or diammonium phosphate are used. Harvesting is planned for between ages 12 and 15, with coppice regeneration for at least two rotations.

McDermott, R.E. 1954. Effects of saturated soil on seedling growth of some bottomland hardwood species. Ecology 35(1):36-41.

This study focuses on seedling survival in saturated soils. Young seedlings (less than l-month-old) of American elm, winged elm, red maple, sycamore, hazel alder, and river birch were subjected to saturated soil conditions for periods of 0, 1, 2, 4, 8, 16, and 32 days. Each treatment was applied to 20 seedlings in four pots of five seedlings per pot. After flooding, the seedlings were kept at or above field capacity under conditions of about 50% sunlight and at high soil temperatures. Heights of the seedlings were measured at the end of 32, 42, and 52 days. Compared to the no-flooding controls, all species showed patterns of stunting in height growth. River birch showed evidence of stunting for all saturation periods greater than 1 day, and red maple was stunted by all but the 4-day saturation period. Both species recovered rapidly in well-drained soil conditions. Sycamore was significantly stunted only by the 32-day treatment, but recovered fairly rapidly. American elm was not affected by 1 or 2 days of saturation, had minor stunting after 4 days of saturation, and was permanently stunted by 8-, 16-, and 32-day saturation periods. Winged elm showed a beneficial effect of a l-day saturation; 2, 4, and 8 days had no apparent effect, and 16 and 32 days of saturation had a negative effect on growth. Hazel alder height growth was promoted by all saturation periods except 32 days, for which no significant effect was found. Survival for hazel alder after 32 days saturation was only 40%, which is unusually low, compared to 100% survival for red maple, the elms, and river birch, and 95% for sycamore.

McElwee, R.L. 1965. Direct seeding hardwoods in river bottoms and coastal plains. Pages 110-115 <u>in</u> Proceedings of the direct seeding workshops, Alexandria, LA, and Tallahassee, FL.

In this symposium presentation, the author addresses three questions: (1) Why direct seed? (2) What are some important considerations for direct seeding? and (3) Can we regenerate bottomland hardwood areas by direct seeding based on current knowledge of the subject? Direct seeding is advantageous in some bottomland situations because it costs about 25%-33% as much and requires less labor than hand-planting, which is often required in bottomland areas because of saturated soils. The effects of root disturbance from lifting and outplanting hardwood seedlings are also eliminated. Important considerations for direct seeding include species, site, and equipment available. Most important bottomland species perform better an sites that have been disked or bladed so that mineral soil is exposed. Most species do better in full sunlight, and require protection from seed predators. Enough is known about direct seeding for successful application in some cases, but more needs to be learned about species-site relationships; what site preparation is needed; collection and storage of seed; sowing rates; and protection from rodents.

McKnight, J.S., and R.L. Johnson. 1966. The techniques of growing hardwoods. Forest Farmer 25(7):59-68.

Management of southern hardwoods, including initial planning, protection, improvement of abused stands, thinning, harvesting systems, and artificial regeneration, is discussed. Informative tables are presented on utility classes; lo-year average diameter growth rates for 13 species and species groups in unmanaged stands; expected regeneration following harvest cutting systems in different species associations; soil suitability by species and physiographic zones; and planting information. The latter table contains information for 9 species or species groups on recommended length for root pruning, top length, and root collar diameter; adaptability to machine planting; response to fertilizer; usual first year growth: suitability for wet sites; and susceptibility to browsing and insect damage, The section on artificial regeneration lists five major rules that have been developed: (1) match species to sites (the soil suitability and physiographic zones are referred to as guidance); (2) prepare the planting site properly (which means removal of competing vegetation and, in abandoned fields, subsoiling); (3) use good planting stock; (4) plant properly: hardwood seedlings are easily damaged by exposure of roots to drying or planting at improper depths; and (5) care for the new plantation properly: control of weeds increases the early growth of all species, especially cottonwood. More needs to be learned about plantation establishment on degraded agricultural fields, optimal spacing, and direct seeding.

Moore, W.H. 1950. Survival and growth of oaks planted for wildlife in the flatwoods. U.S. Forest Service Research Note SE-286, Asheville, NC. 4 pp.

This research note reports on an experiment to assess the potential for creation of hammocks. Two-year-old live oak and laurel oak seedlings were planted in a cut-over pine flatwoods area in Charlotte County, FL. The predominant soil series in the area are the Immokalee (pine-palmetto), which are imperfectly drained acid sands with an organic-stained pan, and Charlotte (wet prairie), which are poorly drained shallow sands over calcareous materials; both soils are saturated much of the year. Treatment plots were established to compare the two oak species; sites (pine-palmetto versus wet prairie); livestock grazing (grazed versus ungrazed); and site preparation (bedding versus tilling). Beds were 4-5 m across, 45-60 cm high, well-drained, and devoid of vegetation. After 8 years, survival of live oak was 95% and laurel oak, 76%. No significant differences were found between sites, site preparation, and grazing treatment. The better survival of live oak may have been due to the unusually dry year following outplanting; live oak appeared better able to survive on the drier planting sites. Height growth was influenced by species, site preparation (the most important factor), and grazing treatment. Trees on tilled plots grew little (averaging only 0.1 m/yr). On beds, live oak averaged 2.1 m after 8 years and laurel oak, 1.3 m. Both species grew better on ungrazed plots; no significant difference was found between the pine-palmetto and wet prairie sites. Results indicated that bedding would be required to establish oaks in the low flatwoods of south Florida.

Nawrot, J.R., and S.C. Yaich. 1983. Slurry pond forestation: potential and problems. Pages 180-194 in Proceedings of the third annual conference on better reclamation with trees. Purdue University, Terre Haute, IN.

The paper discusses factors important to reforestation efforts on inactive slurry impoundments in Illinois and Indiana. Techniques for correcting problems associated with acid-base balance, surface stability, and moisture zones are covered. Earlier studies had revealed that hydrophytic species such as baldcypress and river birch survived well in moist soil zones near impoundment decant areas, and exhibited growth rates comparable to those of individuals growing in natural soils. Other species expected to exhibit good survival and growth include green ash, pin oak, swamp white oak, persimmon, silver maple, black locust, and sycamore. The authors note the value of black locust as a nurse crop for marginal sites; a litter layer and organic enriched zone extending 1.5-2 inches into the slurry surface occurred on a 25-year-old inactive site. Because of the highly unpredictable site conditions that may exist within various slurry impoundments because of coal-seam geology, mining and preparation practices, disposal management, and the period and extent of weathering and leaching, numerous factors should be evaluated prior to planting to avoid poor planting success or complete failure. These factors include hydrogeochemical conditions, nutrient and neutralization amendment requirements and application, organic matter enhancement, moisture extreme regulation, and temperature moderation.

Nelson, T.C. 1957. Rooting and air-layering some southern hardwoods. In Proceedings of the fourth southern conference on forest tree improvement; January 8-9, 1957; Athens, GA.

This paper summarizes studies that have been underway at the Athens-Macon Research Center of the Southeastern Forest Experiment Station. The studies had two main objectives: (1) to increase the number of species that can be successfully planted from cuttings in the Georgia Piedmont; and (2) to develop methods of vegetative propagation necessary for work in hardwood genetics and tree improvement. Propagation in nursery beds through rooting of hardwood cuttings has been successful for cottonwood, sycamore, and yellow-poplar, though only the first two species were then successfully out-planted. A half-acre out-planting of cottonwood cuttings on a bottomland site near Athens, GA, had a 1-year survival of 88% and an average height of 7 ft. The best trials with sycamore had 65% survival and a maximum height growth of 8 ft after one growing season. Best survival and growth of sycamore were obtained from butt-cuttings. Softwood cuttings of yellow-poplar, sweetgum, and water oak planted in nursery beds have been unsuccessful. Tests are now underway with sycamore cuttings to test the effect of various site-preparation techniques on initial survival and growth of cuttings. Cottonwood has been the only species to show a relatively high percentage of success with first attempts at air-layering. Some success was obtained with sycamore, green ash, and sweetgum, but not with yellow-poplar, southern red oak, cherrybark oak, red maple, and flowering dogwood.

Philo, G.R. 1982. Planting stock options for forestation of surface-mined lands. Pages 65-74 in Post-mining productivity with trees. Proceedings of a 1982 seminar in the Department of Botany; Southern Illinois University at Carbondale.

In this paper, factors affecting the choice of planting stock in relation to forestation of surface-mined lands are discussed. Good spring establishment of trees in southern Illinois can be obtained with bare-root seedlings for most of the species commonly available at State and private nurseries. Direct seeding of large-seeded species is also recommended since this practice can extend the planting season into fall, allows for selection of seed source, and cultivates good root form that should enhance the short- and long-term growth of trees. Exceptional establishment rates were noted for the following oaks: black, bur, pin, red, shingle, and particularly Shumard and chestnut. Black walnut from direct seeding also performed well, especially in regard to the root form of established seedlings. Seeded hickory exhibited only moderate success although results were variable. Smaller-seeded species, such as black cherry, persimmon, and hackberry, have exhibited poor establishment rates. For those species not readily established with bare-root seedlings or seed, container seedlings may be appropriate. Inherent in any container system is a degree of distortion of the seedling roots, which could restrict tree growth. The degree of success usually achieved with bare-root stocks or direct seeding and the relatively low cost of these methods have typically led to their use in surface-mined reclamation. On the other hand, container stock may be appropriate when inoculating seedlings with mycorrhizal fungi or other organisms to enhance survival and growth. For bare-root stock, the author recommends pruning taproots to 20 cm, lateral roots to 5 cm, and shoots of hardwoods to 20 cm to facilitate handling and planting.

Putnam, J.A., G.M. Furnival, and J.S. McKnight. 1961. Management and inventory of southern hardwoods. U.S. Forest Service Agriculture Handbook No. 181. 101 pp.

This handbook provides guidance for management and inventory of both bottomland and upland hardwoods throughout the Southern United States. General topics include (1) the forest, (2) preliminary management, (3) advanced management, and (4) inventory. A selected bibliography with 175 references is also included. The first section contains a good discussion of species-site relationships, and subsections on species, stand origins, damaging influences, and utilization. Most of the rest of the handbook is geared toward the management of existing hardwood forests. Planting and direct seeding are not covered. Management topics include reconnaissance, boundary location, protection, compartmentation, timber stand improvement, the first cut, and stocking and growth considerations. A useful table on southern hardwood species and chief softwood associates is provided in the first section. It gives scientific and several common names for each species and information on occurrence in bottomlands and in uplands, growth rate, shade tolerance, reproduction, susceptibility to damage, value and primary uses, and general remarks.

Rafaill, B.L., and W.G. Vogel. 1978. A guide for vegetating surface-mined lands for wildlife in eastern Kentucky and West Virginia. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/84, Washington, DC. 89 pp.

This document contains useful information on species of trees and vegetation suitable for revegetation of surface-mined areas, including availability of plants and planting and seeding methods.

Raisanen, D.L. 1982. Survival of selected tree species on sites reclaimed to various reclamation standards. Pages 93-102 in Post-mining productivity with trees. Proceedings of a 1982 seminar in the Department of Botany; Southern Illinois University at Carbondale.

This paper gives results of a study of 26 plots planted in the spring of 1981 at five surface-mined and reclaimed sites in southern Illinois to evaluate tree survival relative to species and treatments. Tree species included black walnut, black cherry, baldcypress, green ash, hackberry, pin oak, red oak, silver maple, sweetgum, and sycamore. Treatments consisted of application of a fertilizer tablet and a herbicide, planting of seedlings into four different herbaceous cover mixtures, and ripping to a depth of 24 inches: Species were mechanically planted as bare-root seedlings in March 1981; a survival count was made in the fall. Survival rates for the above species ranged from 35% for black cherry to 91% for silver maple. Baldcypress had a survival rate of 45% and hackberry, 46%, and all others were ≥ 59%. Herbicide use increased species survival by 80%. Amizine herbicide (a mixture of Amitrol-T, a post-emergent, and Simizine, a pre-emergent) was applied at 4 lb of active ingredient per acre. The results of fertilization and ripping were inconclusive. Survival rates of the trees grown on three of the four herbaceous cover mixtures were about the same (58%, 59%, and 61%); the survival rate on one mixture was somewhat less, at 51%. The results of this study identified species selection, use of herbicides, and quality planting procedures as important factors in successful plantings.

Richards, T.W. [no date]. Establishing trees by direct-seeding. Reclamation news and views. Cooperative Extension Service. University of Kentucky, Lexington, KY. 6 pp.

Direct-seeding as an alternative and supplement to planting seedlings is discussed in this paper. Advantages of direct seeding include lower labor costs, less planting time per acre, greater species availability, longer planting season, and less chance of root deformity. The author notes that reports of direct-seeding failures are common in the literature and that some references discourage this method; however, he points out that most failures are a result of improper handling and poor planning. Species that have direct-seeded well on surface-mined lands are discussed. The best are the larger-seeded species, including many oaks, black walnut, and Chinese chestnut, but other species may have application in direct-seeding use. Seeding trials have been limited by seed availability and many species have not been sufficiently tested.

Richards, T.W., R.F. Wittwer, and D.H. Graves. 1982. Direct-seeding oaks for surface-mine reclamation. Pages 57-62 in Post-mining productivity with trees. Proceedings of a 1982 seminar in the Department of Botany; Southern Illinois University at Carbondale.

Results are given by the University of Kentucky Department of Forestry for direct-seeding studies on surface-mined land. A consistent pattern of successful establishment and growth has been shown for a variety of oak species, including northern red oak, pin oak, chestnut oak, bur oak, and sawtooth oak. Proper choice of species for specific site conditions is important. Germination and survival can be improved by amendments to the site, such as mulch or mulch and fertilizer. Herbaceous competition is also an important factor affecting long-term survival and growth. Use of a mechanical planter for row-seeding in mine soils can shorten planting time and reduce labor costs; use of spray nozzles on the planter for herbicide application can increase the efficiency of the planting operation.

Robertson, D.J. [1985]. Sink Branch: stream relocation and reclamation by the Florida phosphate industry. Florida Institute of Phosphate Research, Bartow, FL. Draft Final Report (Unpublished). 61 pp.

This report describes follow-up monitoring and reevaluation of an experimental project at Sink Branch (Polk County, FL). Mobil Chemical Company established the project in December 1979 when 0.3 km of Sink Branch, a tributary of the Peace River, was diverted into an artificial channel excavated on phosphate-mined land. Although the study addressed hydrologic and aquatic factors, its primary purpose was to test methods to reestablish a riparian forest along the new channel. The study, conducted on a l-ha area of reclaimed land, included four treatments: application of two different-sized layers of organic soil (0.5 and 1 ft), fertilization, and a no-treatment control. Tree spaded, potted, and bare-root seedlings were planted. Species planted included sweetgum, live oak, Florida elm, slash pine, sweetbay, red maple, baldcypress, green ash, and dogwood. Irrigation water was applied. Three years after planting, the overall survival rate was 29%; the site contained 213 trees per acre, including nine hardwood and one coniferous species. This was sufficient to satisfy the wooded wetland reclamation requirements of Florida, which call for a minimum of 200 indigenous hardwood and coniferous trees per acre. Survival varied among species, planting stocks, and treatments; the responses warrant additional study before conclusions can be reached. Except for slash pine, none of the species exhibited significant differences in growth using the various treatments. The pines responded best in mulched plots, and grew less rapidly in the fertilized and control plots.

Ruesch, K.J. 1983. A survey of wetland reclamation projects in the Florida phosphate industry. Dames and Moore, Lakeland, FL, and Florida Institute of Phosphate Research, Bartow. 59 pp. t appendixes.

This survey identifies (maps provided) and summarizes 35 wetland reclamation projects in the Florida phosphate industry as of Spring 1983. Information was obtained through 51 questionnaires mailed to individuals or organizations, and included size, location, project goals, revegetation methods, plant survival, monitoring, and techniques that failed or were highly successful. Most of the projects were also field inspected. Of the total, 20 projects were completed, 10 were in various stages of construction, and plans had been completed for 5 others. Most of the wetland projects lacked quantitative monitoring and the success of many techniques was not well documented. One apparently successful technique which was frequently used was spreading a layer of organic soil obtained from another wetland to encourage the reestablishment of wetland vegetation.

Rushton, B. 1983. Examples of natural wetland succession as a reclamation alternative. Pages 148-189 in D.J. Robertson, ed. Reclamation and the phosphate industry. Proceedings of a symposium; 26-28 January, 1983; Clearwater Beach, FL. Florida Institute of Phosphate Research, Bartow.

Natural succession occurring on four clay-settling ponds after 2 to 60 years and one 40-year-old control area is discussed. Field measurements were taken at each site on trees and shrubs (including seedlings), herbaceous vegetation, accumulated litter biomass, leaf area index, optical density, and water depth. Succession was found to be taking place, but some sites were in an arrested willow stage, possibly because seeds for the next successional stage were unable to reach the site or become established. Only one site (30 years old) had typical bottomland hardwood vegetation developing, and this only occurred on parts of the site that were periodically inundated. It was concluded that improved seeding and control of hydroperiod may provide means for establishing wetland forests on reclaimed clay-settling pond sites.

Schrand, W.D., and H.A. Holt. 1983. Herbicides and plantation establishment on reclaimed mined lands. Pages 146-157 <u>in</u> Proceedings of the third annual conference on better reclamation with trees. Purdue University, Terre Haute, IN.

This paper discusses the use of selected herbicides for weed control in forest and mine-land revegetation, and provides a bibliography. Herbicides covered include Princeps 80W (simazine); Amitrole-T (amitrole); Dowpon M (dalapon); Roundup (glyphosate); Kerb 50W (pronamide); 2, 4-D; Sulflan; Oust; and Poast. Herbaceous and woody plants exhibit various levels of tolerance to different herbicides. In addition, application rates and environmental conditions can determine the degree of success from site to site. Performance of the herbicides for site-specific test conditions are described. The cost of herbicides and the legal implications of use inconsistent with label instructions are important considerations.

Seifert, J.R., P.E. Pope, and B.C. Fischer. 1985. The effects of three levels of site preparation on planted swamp chestnut oak on a poorly drained site. U.S. Forest Service General Technical Report SO-54, New Orleans, LA.

Swamp chestnut oak seedlings were planted on a poorly drained, upland flat site following three levels of site preparation. The soil type was Avonburg-Clermont (a fine-silty mixed mesic type), and the site had been grazed prior to establishment of the study. Depth to a fragipan varied from 30 to 40 inches and seasonal water table varied from l-3 ft. The site preparation treatments were disking, disking and bedding, and control. Seed was collected within a lo-mile radius of the study site and grown for 1 year in a nursery. Seedlings were hand-planted on a 10 by 10 ft spacing. Weed control was accomplished by treating areas around each seedling with glyphosate and simazine, and mowing untreated areas within rows. After 3 years, plantation survival averaged 89% for all treatments and was not influenced by site preparation; after 5 years, survival had dropped to 83%. Survival after 5 years was 15% lower for control plots compared to the other two treatments, but the difference was not statistically significant. After 5 years, mean height was 150 cm for the control plots, 165 cm for the disked plots, and 142 cm for the disked and bedded plots. In the fifth year, both height and diameter increments were significantly greater for the disked and disked and bedded plots compared to the control plots.

Sharitz, R.R., and L.C. Lee. 1985. Limits on regeneration processes in southeastern riverine wetlands. Pages 139-143 in Riparian ecosystems and their management: reconciling conflicting uses. U.S. Forest Service General Technical Report RM-120, Fort Collins, CO.

This paper presents data from wetland regeneration studies on the Savannah River floodplain in South Carolina. Research showed that although tree seed production seemed adequate, microsite factors and water-level changes limited regeneration success. Low seed viability, especially for baldcypress, seemed to be an important limiting factor. Release of seeds for both baldcypress and water tupelo peaked in November. The recovery of marked seeds released into the floodplain environment revealed that potentially more than 50% of the seeds were retained within 500 m of the parent tree. Review of existing literature suggested that reduced carbohydrate storage may be a major factor contributing to the eventual decline of baldcypress seedlings and mature trees in thermally impacted areas (i.e., discharges of heated water from the cooling systems of nuclear reactors) of the Savannah River floodplain forest. The natural establishment, development, and maintenance of floodplain forests in the Southeast is largely dependent on the coincident availability of viable seeds coupled with low water levels during periods in the growing season when germination and seedling establishment can occur. Managed water levels have generally precluded establishment and maintenance of important tree species on the Savannah River floodplain. Additional research is needed to establish watershed management methods that will satisfy the requirements of floodplain forests.

Silker, T.H. 1948. Planting of water-tolerant trees along margins of fluctuating-level reservoirs. Iowa State College Journal of Science 22:431-447.

The results of trial plantations with eight species along the margins of Tennessee Valley Authority reservoirs in the lower Tennessee River Valley are described. Species planted were baldcypress, water tupelo, sweetgum, green ash, water oak, willow oak, Atlantic white cedar, and sycamore. The plantations were established either in the upper drawdown zone of the reservoirs (soils intermittently covered with 1-3 ft of water at normal pool level) or in surcharge zones (soils 1-15 ft above normal pool level that are flooded occasionally). Some plantations were established with nursery-grown seedlings, and in other cases with transplanted wild seedlings. Five-year development of plantations of all eight species in the surcharge zone are discussed by cover and soil conditions, water-level conditions, and species. Average survival was 60% or better for all species except Atlantic white cedar; the poor survival (11%) of the latter species was attributed to the poor quality of the wild planting stock used. Height growth ranged from 3.3 ft for water tupelo to 14.3 ft for sycamore in broom sedge cover areas; most species obtained their best height growth in sites with woody cover rather than broom sedge or hydrophytic weed cover. Only baldcypress, water tupelo, and Atlantic white cedar were planted in upper drawdown areas. Survival of baldcypress and water tupelo plantations after 11 or 12 years was 88% or better. Atlantic white cedar had 58% survival after 9 years, and the largest rate of annual height growth (2.5 ft/year), followed by baldcypress (1.9 ft/year), and water tupelo (1.8 ft/year).

Stubbs, J. 1963a. Planting hardwoods on the Santee Experimental Forest. Southern Lumberman 207:135-136, 138.

Planting trials of yellow-poplar, white ash, swamp chestnut oak, Shumard oak, and cherrybark oak on the Santee Experimental Forest, near Charleston, SC, are briefly summarized. Stream bottom and terrace sites were planted, but only results from terrace sites are discussed. Soil types on the planted sites include Coxville loam and phosphatic variants of Bayboro clay loam and Chastain very fine sandy loam. The sites previously supported stands of good quality hardwoods dominated by cherrybark and Shumard oaks, yellow-poplar, sweetgum, white and swamp chestnut oaks, and white ash. Prior to planting, all merchantable wood was removed; the remaining culls were killed using 2,4,5-T, but no further site preparation was done. Planting was done during winter using a lo-inch planting bar and root-pruned l-year-old seedlings. Average survival for all species was 76% after one growing season. Survival after 5 years ranged from 46% for cherrybark oak to 81% for white ash. In two trials, planted in consecutive years, yellow-poplar had the best average height growth after 5 years (6.7 ft), and cherrybark oak had the lowest (4.6 ft). Yellow-poplar did much better on well-drained sites with deep topsoil; survival on such sites was 89% and dominant trees reached 15 ft. Cherrybark and Shumard oak showed extreme variation in individual seedling height growth, which could not be explained. Survival and growth of swamp chestnut oak were generally better than the red oaks and compared favorably with yellow-poplar on most sites.

Stubbs, J. 1963b. Survival and growth of sweetgum, Shumard oak, and spruce pine planted on a creek bottom site in the Carolina coastal plain. Journal of Forestry 61:386-388.

Results are given of a study of sweetgum, Shumard oak, and spruce pine planted in an area of cleared forest on a stream terrace (second bottom) near Charleston, SC. Plots were planted in January 1955 with graded 1-0 seedlings raised from local seed. A conventional 10-inch planting bar was used. Several planting spacings were evaluated; these were 4 by 4, 6 by 6, and 8 by 8 ft. After five growing seasons, any effects of spacing were not evident. Sweetgum had 91% survival and averaged 12.5 ft in height; corresponding values for Shumard oak were 72% and 5.2 ft, and spruce pine 48% and 7.7 ft. The breaking up of dead overstory trees, which were killed by herbicide treatment after first clearing the area of all merchantable timber, caused considerable damage to the planted trees. Vines were major competitors, and when they were supported by saplings, some stem deformation occurred. Planted sweetgum exhibited vigorous growth and few individuals were overtopped by competing vegetation. Other desirable features of sweetgum that made this species particularly amenable to management include (1) production of large quantities of easily collected seed most years, (2) good seed viability, (3) easily grown nursery stock, and (4) easy planting. The authors note that without cleaning and weeding, only the sweetgum plantings resulted in well-stocked, homogeneous stands. Patches of natural sweetgum, yellow-poplar, and oak of both seedling and sprout origin often outgrew the planted trees.

Swenson, E.A., and C.L. Mullins. 1985. Revegetating riparian trees in southwestern floodplains. Pages 135-138 <u>in</u> Riparian ecosystems and their management: reconciling conflicting uses. U.S. Forest Service General Technical Report RM-120, Fort Collins, CO.

Managers have generally been unsuccessful in using conventional techniques to replace riparian trees, and in this paper an alternative using large cuttings is discussed. Experiments with Rio Grande cottonwood, narrowleaf cottonwood, and Goodding willow showed that placing large, dormant cuttings into holes predrilled to the depth of the growing season water table can be a simple and inexpensive method of revegetating floodplains. The cuttings were obtained from saplings with a basal diameter of 2-3 inches and a height of up to 20 ft; all side branches were removed, and the tops were cut back to a 3/8-inch diameter. Success of such plantings, however, is unlikely unless prolonged flooding does not occur at the site and beaver and livestock can be controlled.

Thompson, R.L., W.G. Vogel, G.L. Wade, and B.L. Rafaill. 1986. Development of natural and planted vegetation on surface mines in southeastern Kentucky. Pages 145-153 <u>in</u> New horizons for mined land reclamation. Proceedings of the American Society for Surface Mining and Reclamation, Princeton, WV.

Descriptive studies made of the flora on five 17- to 20-year-old surface-mined areas that originally had been partly or entirely planted with herbaceous and woody species are covered in this paper. A rich flora was found on these mines as a result of natural secondary succession together with the artificial plantings. Important invading species common at all or most of the sites were red maple, yellow-poplar, black locust, sourwood, blackgum, and sycamore. Changes in hydrology and rooting depth, associated with old mining practices, seemed to have created forest-site conditions that were sometimes more mesic and potentially more productive than the premining condition. Although additional studies are recommended, the data revealed that potentially productive forest ecosystems are reestablishing on some of the older surface-mined sites in southeastern Kentucky.

Toliver, J.R. 1986. Survival and growth of hardwoods planted on abandoned fields. Louisiana Agriculture 29(2):10-11.

The article reports on trials with six bottomland hardwood species that were planted on old soybean fields at Thistlethwaite Game Management Area in St. Landry Parish, LA. Two soil types, Baldwin and Dundee silty clay loams, were represented in the plantations. Both types are high in fertility, but the Baldwin soil type has a higher clay content and lower permeability. Pecan, sweetgum, sycamore, and cherrybark oak seedlings were planted on soybean stubble after harvest in February. Green ash and baldcypress were planted on disked soybean fields that had lain fallow for 2 years. All seedlings were l-year-old bare-rooted stock that had tap roots pruned to a length of 6-8 inches, and were hand-planted on a 10 by 10 ft spacing using a planting bar. Weed control generally consisted of disking and/or mowing between trees two or three times during the growing season for the first 3 years, and an application of herbicide (Roundup) sprayed around individual trees in June or July. After the third year, the plantations were mowed at least once each year. After 5 years, sycamore survival averaged 92% and mean height averaged 13.6 ft for two plantations; cherrybark oak survival averaged 74% and height, 6.4 ft for three plantations; survival and mean height were 48% and 2.7 ft for pecan and 46% and 6.8 ft for sweetgum. After 3 years, green ash had 97% survival and a mean height of 7.9 ft on one plantation. After 2 years baldcypress had 98% survival and a mean height of 4.1 ft.

Toliver, J.R., R.C. Sparks, and T. Hansbrough. 1980. Effects of top and lateral root pruning on survival and early growth on three bottomland hardwood species. U.S. Forest Service Tree Planters' Notes 31(3):13-15.

This paper describes one- and five-year results of planting trials with five combinations of top- and/or root-pruned seedlings of water oak, willow oak, and pecan. Out-planted seedlings of all species had excellent survival (96%) after 1 year, and the differences in survival between the various treatments of root and/or top pruning were minor. Average height growth after 1 year was highest for water oak (51.0 cm), followed by willow oak (49.0 cm) and pecan (26.4 cm). By the fifth year, survival of willow oak and pecan was still greater than 90%, but water oak survival dropped to 82.4%. Willow oak had the greatest average height after 5 years (372.0 cm), followed by water oak (332.2 cm) and pecan (131.0 cm). Overall the differences were minor between the treatments, but the combination of root pruning and top pruning tended to produce the best height growth for all species and is therefore recommended.

U.S. Bureau of Land Management (BLM). 1983. Environmental assessment on state of reclamation techniques on phosphate mined lands in Florida and their application to phosphate mining in the Osceola National Forest. U.S. Bureau of Land Management, Eastern States Office, Alexandria, VA.

This assessment concludes that although there are many studies underway, there is a lack of conclusive data on the ability to reestablish wetland hardwoods on phosphate-mined land in central Florida. The assessment provides a summary of 29 wetland reestablishment studies within the Florida phosphate industry between 1975 and 1982 (most studies were less than 5-years-old).

Vogel, W.G. 1973. The effect of herbaceous vegetation on survival and growth of trees planted on coal-mined spoils. Pages 197-207 in Proceedings of the research and applied technology symposium on mined-land reclamation. Bituminous Coal Research, Inc., Monroeville, PA.

This study examines the effects of herbaceous competition with trees on coal-mine spoils in southeastern Kentucky. Grass alone and grass with legumes were sown concurrently with the planting of trees. After three growing seasons, the herbaceous vegetation, which covered about 95% of the ground, did not significantly affect survival of the trees but greatly suppressed their growth. During the fourth and fifth growing seasons, the growth of trees in plots dominated by legumes exceeded growth in the other treatment plots. Tree growth was suppressed most by grass cover alone.

Vogel, W.G. 1980. Revegetating surface-mined lands with herbaceous and woody species together. Pages 117-126 in Proceedings of trees for reclamation. U.S. Forest Service General Technical Report NE-61, Broomall, PA.

The report covers tests with trees (cottonwood, sycamore, pines) planted with herbaceous species. Results showed there was an increase in tree seedling mortality and retarded tree growth, especially in the first few years after planting. The trees seemed to be most affected by competition for moisture; survival was least affected where spring and summer precipitation was abundant. In some areas, tree survival was reduced by dense stands of some legumes, such as crown vetch, flat pea, and sericea lespedeza. Planting trees in existing stands of herbaceous cover usually resulted in poor survival. Herbicides or scalping to control competition was suggested, although it was noted that there was little supporting data. Planting trees and seeding herbaceous species in alternate strips was believed to be a feasible method.

Vogel, W.G. 1981. A guide for revegetating coal mine soils in the eastern United States. U.S. Forest Service General Technical Report NE-68, Broomall, PA. 190 pp.

This technical report provides information, recommendations, and guidelines for revegetating land in the eastern United States that has been disturbed by coal mining. The document includes information on a variety of tree species associated with bottomland forest sites, as well as guidance on grading and leveling, seeding practices, planting methods, soil amendments, mulches, soil stabilizers, and erosion control.

Wadsworth, C.A. 1983. The development of techniques for the use of trees in the reclamation of phosphate lands--a project overview. Pages 390-394 in D.J. Robertson, ed. Reclamation and the phosphate industry. Proceedings of Symposium; 26-28 January, 1983; Clearwater Beach, FL. Florida Institute of Phosphate Research, Bartow, FL.

In this project, thirteen research plots, involving 30 species (e.g., laurel oak, sycamore, cottonwood, baldcypress) were planted during 1981. The three main objectives of the project were (1) establish and monitor trial plantings of the most promising tree species on a variety of representative phosphate soils, (2) develop techniques for the direct seeding of sand pine and slash pine on tailing sands, and (3) develop criteria and guidelines for the use of trees to recreate wetland, island, upland, and aquatic habitat on mined wastes. Initial survival for the various species was reported, but since the data were only for about one growing season, no conclusions on the success of the project could be drawn.

Waldrop, T.A., E.R. Buckner, and A.E. Houston. 1983. Suitable trees for the bottomlands of west Tennessee. Pages 157-160 in Proceedings of the second biennial southern silvicultural research conference. U.S. Forest Service General Technical Report SE-24, New Orleans, LA.

This study examines three species: sweetgum, green ash, and sycamore; two seed sources for sweetgum and sycamore; and three cultural treatments (fertilization, disking, and mowing) to determine which combination(s) would be best suited to abandoned agricultural fields. The study site was on the floodplain of a tributary to the Wolf River in southwest Tennessee. The fields were farmed for soybeans until 1979; flooding occurred less than annually, but enough to make soybean planting risky. The soils were silt loam, 5.4-6.6 pH, and lower in phosphorus and potassium than most soils used for agricultural purposes. Seedlings were planted in the spring of 1980. Five species/seed source combinations (sycamore, green ash, sweetgum from the Virginia coastal plain, and sweetgum and sycamore from the Louisiana gulf coast) were tested, with fertilization as the main treatment. Disking and mowing were tested at the subplot level. After three growing seasons, survival was over 90% for all treatments, and there were no significant survival differences among the five species/seed source combinations. Survival was slightly lower in the fertilized plots (93% versus 95%), perhaps due to the exceptionally dry season following planting and fertilization in 1980. Seed source did not significantly affect height growth after three growing seasons. Sycamore grew the fastest (mean height of 9.0 ft after three growing seasons), followed by green ash (6.1 ft) and sweetgum (5.4 ft). Fertilization increased the height growth of green ash by 25%, sycamore, 19%, and sweetgum, 16%. Disking improved growth significantly over mowing for all species. Response was greatest for sycamore (52%), followed by green ash (50%) and sweetgum (26%). Disking and fertilization both increased growth when applied alone, but combining the two did not produce a significant growth advantage, especially for sycamore.

Walker, L.C., and K.G. Watterston. 1972. Silviculture of southern bottomland hardwoods. School of Forestry Bulletin 25. Stephen F. Austin University, Nacogdoches, TX. 79 pp.

This handbook covers bottomland hardwood silviculture in the Mississippi River Delta, Coastal Plain Alluvial Valley, and Piedmont Alluvial Valley regions. Each of the three regions is briefly described in the first section, with the Mississippi River Delta Region covered in greatest detail. The next section contains a general description of injurious agents in southern bottomland hardwood forests, including decay caused by fire, beaver damage and increment coring, insects, grazing, competition, windthrow, and flooding effects. A useful key to some of the more important types of insect damage is provided in this section. The final section covers the silviculture of selected species or species groups, including cottonwood, blackwillow, oaks, sweetgum, water tupelo, sycamore, and yellow-poplar. The species subsections vary considerably in depth of treatment, but typically cover growth, site index and/or vigor, and means of regeneration. The handbook contains 119 references, which should be of considerable use to individuals needing more information on a particular species or injurious agent.

Wenger, K.F., editor. 1984. Forestry handbook (2nd edition). John Wiley and Sons, New York. 1,335 pp.

This is a major reference book of data and methods in all phases of forestry and allied fields directed primarily at the practicing field forester. For those interested in forest reestablishment, sections on forest insect and disease management, fire management, and silviculture should be of interest. The section on silviculture includes information on stand regeneration, site preparation and management of problem vegetation (including a herbicide selection guide), and managing for natural regeneration.

NON-ANNOTATED ENTRIES

OTHER BIBLIOGRAPHIES

Boyd H. 1948. Bibliography of hardwood planting. U.S. Forest Service Southern Forest Experiment Station, New Orleans, LA. 9 pp.

Hall, L.C. 1968 (Revised 1971). Bibliography of freshwater wetlands ecology and management. Wisconsin Department of Natural Resources Research Report 33, Madison. 231 pp.

Miller, W.D. 1967. An annotated bibliography of southern hardwoods. North Carolina Agricultural Experiment Station Technical Bulletin 176. 358 pp.

Miller, W.D. [No date]. An annotated bibliography of hardwood regeneration. School of Forestry Hardwood Research Program Technical Report 30. North Carolina State University, Raleigh. 93 pp.

Miller, W.D. [No date]. An annotated bibliography of hardwood silvics. School of Forestry Hardwood Research Program Technical Report 31. North Carolina State University, Raleigh. 82 pp.

Nelson, I.L. 1953. References on the management of bottomland hardwoods and baldcypress. U.S. Forest Service Southern Forest Experiment Station, New Orleans, LA. 11 pp.

Spohrer, M.L. 1976. Edaphic requirements of bottomland hardwoods and the effects of fluctuation and sedimentation. A bibliography with abstracts. Louisiana Cooperative Wildlife Research Unit Special Publication No. 2, Baton Rouge, LA. 27 pp.

Stransky, J.J., and H.E. Daniel. 1964. References on effects of flooding on forest trees. U.S. Forest Service Research Note SO-12, New Orleans. 5 pp.

Wolf, R.B., L.C. Lee, and R.A. Sharitz. 1986. Wetland creation and restoration in the United States from 1970 to 1985: an annotated bibliography. Wetlands 6(1):1-88.

HYDROLOGY, FLOODING EFFECTS, TOLERANCE

Bedinger, M.S. 1978. Relation between forest species and flooding. Pages 427-435 in P.E. Greeson, J.R. Clark, and J.E. Clark, eds. Wetland functions and values: the state of our understanding. American Water Resources Association.

Broadfoot, W.M., and E.R. Toole. 1957. Drought affects southern hardwoods. U.S. Forest Service Southern Forest Experiment Station Note 111, New Orleans, LA.

Broadfoot, W.M., and E.R. Toole. 1959. Hardwoods recovering from drought. U.S. Forest Service Southern Forest Experiment Station Note 119, New Orleans, LA.

Burma, P.G., and J.C. Day. 1975. Reservoir induced plant community changes; a methodical explanation. Journal of Environmental Management 3:219-250.

Grizzell, R.A. 1976. Flood effects on stream ecosystems. Journal of Soil and Water Conservation 31:283-285.

Harms, W.R., H.T. Schreuder, D.D. Hook, C.L. Brown, and F.W. Shropshire. 1980. The effects of flooding on the swamp forest in Lake Ocklawaha, Florida. Ecology 61(6):1412-1421.

Hook, D.D. 1984. Waterlogging tolerance of lowland tree species of the South. Southern Journal of Applied Forestry 8(3):136-149.

Kozlowski, T.T., editor. 1976. Water deficits and plant growth: soil water measurements, plant responses and breeding for drought resistance. Academic Press, New York. 383 pp.

Kozlowski, T.T., editor. 1984. Flooding and plant growth. Academic Press, Orlando, FL. 356 pp.

Loucks, W.L. 1987. Flood-tolerant trees. Journal of Forestry 85(3):36-40.

McKnight, J.S., D.D. Hook, O.G. Langdon, and R.L. Johnson. 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the Southern United States. Pages 29-65 in J.R. Clark and J. Benforado, eds. Wetlands of bottomland forests: proceedings of a workshop on bottomland hardwood forest wetlands of the southeastern United States. Elsevier Scientific Publishing Company, New York.

Mitsch, W.J., W. Rust, A. Behnke, and L. Lai. 1979. Environmental observations of a riparian ecosystem during flood season. Resource Report No. 142, Water Resource Center, University of Illinois at Urbana.

Mitsch, W.J., and W.G. Rust. 1984. Tree growth responses to flooding in a bottomland forest in northeastern Illinois. Forest Science 30(2):499-510.

Noble, R.E., and P.K. Murphy. 1975. Short term effects of prolonged backwater flooding on understory vegetation. Castanea 40:228-238.

Pierce, R.S. 1975. Ground water; its nature, properties, and effects on forest growth. Dissertation Abstracts 17(10):2111.

Teskey, R.O., and T.M. Hinckley. 1977. Impacts of water level changes on woody riparian and wetland communities. Volume I. Plant and soil responses to flooding. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-77/58, Washington, DC. 30 pp.

Teskey, R.O., and T.M. Hinckley. 1977. Impact of water level changes on woody riparian and wetland communities. Volume II. The southern forest region. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-77/59, Washington, DC. 46 pp.

Teskey, R.O., and T.M. Hinckley. 1977. Impact of water level changes on woody riparian and wetland communities. Volume III. The central forest region. U.S. Fish and Wildlife Service Biological, Services Program FWS/OBS-77/60, Washington, DC. 36 pp.

Teskey, R.O., and T.M. Hinckley. 1978. Impact of water level changes on woody riparian and wetland communities. Volume IV. Eastern deciduous forest region. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/87, Washington, DC. 54 pp.

Teskey, R.O., and T.M. Hinckley. 1978. Impact of water level change on woody riparian and wetland communities. Volume V. The northern forest region. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/88, Washington, DC. 54 pp.

Thompson, P.M., and R.C. Anderson. 1976. An ecological investigation of the Oakwood Bottoms Greentree Reservoir in Illinois. Pages 45-64 in J.S. Fralish, G.T. Weaver, and R.C. Schlesinger, eds. First central hardwood forest conference. Southern Illinois University at Carbondale. 484 pp.

Whitlow, T.H., and R.W. Harris. 1979. Flood tolerance in plants: a state-of-the-art review. U.S. Army Corps of Engineers Environmental and Water Quality Operational Studies Technical Report E-79-2, Washington, DC. 161 pp.

PLANTPROPAGATION

Anonymous. 1943. Germination of seeds: Field germination of various hardwoods. American Nurseryman 77(6):32.

Bonner, F.T. 1972. Maturation of sweetgum and American sycamore seeds. Forest Science 18:223-231.

Bonner, F.T. 1973. Timing collections of Fraxinus oennsvlvanica Marsh in the southern United States. In Proceedings, volume 1, paper 4, IUFRO International Symposium on Seed; Bergen, Norway. 7 pp.

Bonner, F.T. 1974. Maturation of acorns of cherrybark, water, and willow oaks. Forest Science 20:238-242.

Hartmann, H.T., and D.E. Kester. 1968. Plant propagation principles and practices, 2nd ed. Prentice-Hall Company, Englewood Cliffs, NJ. 702 pp.

Huntzinger, H.J. 1968. Methods for handling black cherry seed. U.S. Forest Service Research Paper NE-102. 22 pp.

Johnson, L.P.V. 1946. Effect of chemical treatments on the germination of forest tree seeds. Forestry Chronicle 22:17-24.

United States Forest Service. 1965. Proceedings of direct seeding workshops; Alexandria, LA, and Tallahassee, FL. U.S. Forest Service Region 8. 151 pp.

Vande Linde, F. 1964. Nursery practice for southern oaks and gums. U.S. Forest Service Tree Planters' Notes 65:24-26.

BALDCYPRESS

Blair, R.M., and M.J. Langlinais. 1960. Nutria and swamp rabbits damage baldcypress plantings. Journal of Forestry 58(5):388-389.

Bull, H. 1949. Cypress planting in Southern Louisiana. Southern Lumberman 179(2249):227-230.

Demaree, D. 1932. Submerging experiments with Taxodium. Ecology 13(3):258-262.

Den Vyl, D. 1961. Some observations on baldcypress in Indiana. Ecology 42(4):841-843.

Ewel, K.C., and H.T. Odum. 1985. Cypress swamps. University Press of Florida at Gainesville. 490 pp.

Faulkner, P., F. Zeringue, and J. Toliver. 1985. Genetic variation among open-pollinated families of baldcypress seedlings planted on two different sites. Pages 267-272 *in* Proceedings of the eighteenth Southern Forest Tree Improvement Conference. Sponsored publication No. 40, Long Beach, MS.

Gooch, F.S. 1953. Nursery culture of cypress. Southern Lumberman 186(2324):37-38.

Gunderson, L.H. 1976. Accelerating secondary succession in cypress stands. Pages 738-762 *in* H.T. Odum and K.C. Ewel, eds. Cypress wetlands for water management, recycling and conservation. Third annual report to the National Science and Rockefeller Foundations. Center for Wetlands, University of Florida at Gainesville.

Gunderson, L.H. 1977. Regeneration of Cypress, *Taxodium distichum* and *Taxodium acendens*, in logged and burned cypress stands at Corkscrew Swamp Sanctuary, Florida.. M.S. Thesis. University of Florida at Gainesville.

Johnson, R.L. 1958. Clip or deep-plant cypress? U.S. Forest Service Southern Forest Experiment Station Note 116, New Orleans, LA.

Klawitter, R.A. 1961. Seedling size affects early survival and height growth of planted cypress. U.S. Forest Service Research Note SE-155. 2 pp.

Krinard, R.M. 1959. No advantage to clipping baldcypress stock. U.S. Forest Service Tree Planters' Notes 36:14.

Krinard, R.M., and R.L. Johnson. 1976. Pl-year growth and development of baldcypress on a flood-prone site. U.S. Forest Service Research Note SO-217, New Orleans, LA. 4 pp.

Krinard, R.M., and R.L. Johnson. 1987. Growth of 31-year-old baldcypress plantation. U.S. Forest Service Research Note SO-339, New Orleans, LA. 4 pp.

Kurz, H., and D. Demaree. 1934. Cypress buttresses and knees in relation to water and air. Ecology 15:36-41.

Kurz, H., and K.A. Wagner. 1953. Factors in cypress dome development. Ecology 34(1):157-164.

Langdon, O.G. 1958. Silvical characteristics in bald cypress. U.S. Forest Service Southeastern Forest Experiment Station Paper 94. 7 pp.

Marois, K.C., and K.C. Ewel. 1983. Natural and management-related variation in cypress domes. Forest Science 29(3):627-640.

Mattoon, W.R. 1915. The southern cypress. U.S. Department of Agriculture Bulletin 272, Washington, DC. 174 pp.

Mattoon, W.R. 1916. Water requirements and growth of young cypress. Proceedings of the eleventh Society of American Foresters.

Mitsch, W.J., and K.C. Ewel. 1979. Comparative biomass and growth of cypress in Florida wetlands. American Midland Naturalist 101(2):417-426.

Odum, H.T., and K.C. Ewel, editors. 1974-1978. Cypress wetlands for water management, recycling and conservation. Annual-reports to the National Science and the Rockefeller Foundations. Center for Wetlands, University of Florida at Gainesville.

Rathborne, J.C. 1951. Cypress reforestation. Southern Lumberman 183(2297):239-240.

Swanson, P.L. 1965. The bald cypresses. American Nurseryman 121(2):7, 72-77.

Vernon, R.O. 1974. Cypress (Taxodium) domes. Science 105(2717):97-99.

Wagner, K., and H. Kurz. 1954. Cypress root and stem modifications in relation to water. Florida State University Studies 13:18-47, Tallahassee, FL.

Welch, W.H. 1931. An ecological study of the baldcypress in Indiana. Pages 207-213 in Proceedings of the forty-first Indiana Academy of Science.

Whitford, L.A. 1956. A theory on the formation of cypress knees. Journal of the Elisha Mitchell Scientific Society 72(1):80-83.

Williston, H.L., F.W. Shropshire, and W.E. Balmer. 1980. Cypress management: A forgotten opportunity. U.S. Forest Service Report 8. 8 pp.

COTTONWOOD

Allen, R.M., and A.L. McComb. 1956. Rooting of cottonwood cuttings. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 151, New Orleans, LA. 10 pp.

Applequist, M.B. 1959. A selected bibliography on cottonwood. Louisiana State University Forest Note 24, Baton Rouge, LA.

Bonner, F.T. 1967. Responses of 1-year-old cottonwood increasing soil moisture tension. U.S. Forest Service Research Note SO-56, New Orleans, LA. 3 pp.

Broadfoot, W.M. 1960. Early growth of planted cottonwood on Delta soils. Mississippi Farm Research 23(10):7.

Broadfoot, W.M. 1960. Cottonwood growth varies with type of soil. Mississippi Farm Research 23(10):7.

Broadfoot, W.M. 1960. Field guide for evaluating cottonwood sites. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 178, New Orleans, LA.

Broadfoot, W.M. 1973. Water table depth and growth of young cottonwood. U.S. Forest Service Research Note SO-167, New Orleans, LA. 4 pp.

Bull, H. 1941. Cottonwood wildings make good planting stock. U.S. Forest Service Southern Forest Experiment Station Note 37, New Orleans, LA.

Bull, H., and H. Muntz. 1943. Planting cottonwood on bottomlands. Mississippi Agricultural Experiment Station Bulletin 391. 18 pp.

Bull, H., and J.A. Putnam. 1940. Early survival of cottonwood and hybrid poplar plantations at Stoneville, MS. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 94, New Orleans, LA. 7 pp.

Bull, H., and J.A. Putnam. 1941. First-year survival and height growth of cottonwood plantations at Stoneville, MS. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 98, New Orleans, LA. 16 pp.

Burkhardt, E.C. 1962. Reforestation breakthrough. Giant plow produces first commercial cottonwood plantation from seed. Southern Lumberman 204(2544):39-40.

Dannenberg, W. 1970. Site and planting requirements for artificial regeneration of cottonwood. Pages 18-27 in The nineteenth annual forest symposium; Louisiana State University, Baton Rouge.

Engstrom, A. 1948. Growing cottonwood from seed. Journal of Forestry 46:130-132.

Gammage, J.L., and L.C. Maisenhelder. 1960. Refrigeration prolongs viability of cottonwood seed. U.S. Forest Service Tree Planters' Notes 43:5-6.

Gammage, J.L., and L.C. Maisenhelder. 1962. Planting cottonwood seed in a nursery. U.S. Forest Service Tree Planters' Notes 51.

Gilmore, A.R., and L.H. Kahler. 1962. Easy way to sow cottonwood nursery beds. U.S. Forest Service Tree Planters' Notes 55:19-20.

Johnson, R.L. 1959. Pruning cottonwood. Southern Lumberman 198(2473):28-29.

Johnson, R.L. 1962. Need control and site preparation for natural regeneration of cottonwood. Proceedings of the fifteenth annual southern weed conference.

Johnson, R.L. 1965. Regenerating cottonwood from natural seedfall. Journal of Forestry 63:33-36.

Johnson, R.L., and E.C. Burkhardt. 1962. Cottonwood seeds on bulldozed strips. U.S. Forest Service Note 135.

Johnson, R.L., and E.C. Burkhardt. 1976. Natural cottonwood stands: past management and implications for plantations. Pages 20-30 in Proceedings of the symposium on the eastern cottonwood and related species.

Johnson, R.L., and R.M. Krinard. 1965. Tips for managing drought-stricken cottonwoods along the lower Mississippi River. U.S. Forest Service Research Note SO-24. New Orleans, LA. 4 pp.

Kaszkurewicz, A. 1973. Establishment and early growth of Populus deltoides. Ph.D. Dissertation. Louisiana State University, Baton Rouge. 312 pp.

Krinard, R.M. 1964. Weed control trials in cottonwood plantations. Mississippi Farm Research 27(5):8.

Krinard, R.M., and R.L. Johnson. 1984. Cottonwood plantation growth through 20 years. U.S. Forest Service Research Paper SO-212, New Orleans, LA. 11 pp.

Krinard, R.M., and H.E. Kennedy, Jr. 1983. Growth, thinning treatments, and soil properties in a lo-year-old cottonwood plantation on a clay site. U.S. Forest Service Research Note SO-302, New Orleans, LA. 4 pp.

Maisenhelder, L.C. 1947. A nursery for cottonwood cuttings. U.S. Forest Service Note 48, New Orleans, LA.

Maisenhelder, L.C. 1951. Planting and growing cottonwood on bottomlands. Mississippi Agricultural Experiment Station Bulletin 485. 23 pp.

Maisenhelder, L.C. 1960. Cottonwood plantations for southern hardwoods. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 179, New Orleans, LA. 24 pp.

Maisenhelder, L.C., and J.S. McKnight. 1968. Cottonwood seedlings best for sites subject to flooding. U.S. Forest Service Tree Planters' Notes 19(3):15-16.

McComb, A.L., and H.S. Lovestead. 1954. Viability of cottonwood (Populus deltoides) seeds in relation to storage temperature and humidities. U.S. Forest Service Tree Planters' Notes 17:9-11.

McKnight, J.S. 1970. Planting cottonwood cuttings for timber production in the South. U.S. Forest Service Research Paper SO-60, New Orleans, LA. 17 pp.

Minckler, L.S., and P.E. Lamendola. 1953. Growth of well -stocked cottonwood stand. U.S. Forest Service Central States Forest Experiment Station Note 75. 2 pp.

Minckler, L.S., and J.D. Woerheide. 1965. One way to establish cottonwood plantations-- a case history. Southern Lumberman 211(2632):177-178.

Moore, H. 1958. Planting cottonwood cuttings. Pages 10-13 in Proceedings of the seventh annual forest symposium; Louisiana State University, Baton Rouge.

Nelson, T.C. 1957. Survival and early growth of an eastern cottonwood plantation on the Piedmont. U.S. Forest Service Tree Planters' Notes 28:9.

Smith, J.H. 1957. Some factors indicative of site quality for black cottonwood. Journal of Forestry 55:578-580.

Switzer, H.D. 1948. The management of cottonwood in the bottomlands of southern Illinois. Southern Lumberman 177(2225):153-157.

Williamson, A.W. 1913. Cottonwood in the Mississippi valley. U.S. Forest Service Bulletin 24. 62 pp.

Wilson, R.E. 1970. Succession in stand of Populus deltoides along the Missouri River in southeastern South Dakota. American Midland Naturalist 83(2):330-342.

OAKS

Adams, J.C. 1983. Water oak regeneration in the south's upland bottomland. Pages 177-179 in E.P. Jones, Jr., ed. Proceedings of the second biennial southern silvicultural research conference. U.S. Forest Service General Technical Report 24, Asheville, NC.

Applequist, M.B. 1959. Growth of planted cherrybark oak in southeastern Louisiana. Louisiana State University Forest Note 26. 2 pp.

Aust, W.M., J.D. Hodges, and R.L. Johnson. 1984. The origin, growth and development of natural, pure, even-aged stands of bottomland oak. Pages 163-170 in E. Shoulders, ed. Proceedings of the third biennial southern silvicultural research conference. U.S. Forest Service Southern Forest Experiment Station, New Orleans, LA.

Beaufait, W.R. 1956. Influence of soil and topography on willow oak sites. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 148, New Orleans, LA. 12 pp.

Bonner, F.T. 1973. Storing red oak acorns. U.S. Forest Service Tree Planters' Notes 24(3):12-13.

Broadfoot, W.M. 1961. Topsoil makes site difference for cherrybark oak. U.S. Forest Service Southern Forest Experiment Station Note 132, New Orleans, LA.

Broadfoot, W.M. 1961. Guide for evaluating cherrybark oak sites. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 190. 9 pp.

Broadfoot, W.M. 1963. Guide for evaluating water oak sites. U.S. Forest Service Research Paper SO-1, New Orleans, LA. 8 pp.

Broadfoot, W.M. 1964. Guide for evaluating willow oak sites. U.S. Forest Service Research Paper SO-13, New Orleans, LA. 7 pp.

Carvell, K.L., and E.H. Tryon. 1961. The effect of environmental factors on the abundance of oak regeneration beneath mature oak stands. Forest Science 7(2):98-105.

Clark, R.H. 1958. Direct seeding of cherrybark oak. Pages 5-9 in Proceedings of the seventh annual forest symposium; Louisiana State University, Baton Rouge.

Francis, J.K. 1980. Nuttall oak acorn production as affected by tree size, degree of thinning, and flooding. U.S. Forest Service Southern Forest Experiment Station Final Report, New Orleans, LA.

Francis, J.K. 1983. Acorn production and tree growth of nuttall oak in a greentree reservoir. U.S. Forest Service Research Note SO-289, New Orleans, LA.

Francis, J.K. 1983. Cherrybark and shumard oaks successfully planted on eroded ridges. U.S. Forest Service Tree Planters' Notes 34(2):28-30.

Francis, J.K., and R.L. Johnson. 1985. Direct-seeded sawtooth oaks (Quercus acutissima Carruth) show rapid growth on diverse sites. U.S. Forest Service Tree Planters' Notes 36(3):3-5.

Hook, D.D. 1969. Influence of soil type and drainage on growth of swamp chestnut oak (Quercus michauxii Nutt) seedlings. U.S. Forest Service Research Note SE-106, New Orleans, LA. 3 pp.

Johnson, R.L. 1975. Natural regeneration and development of Nuttall oak and associated species. U.S. Forest Service Research Paper SO-104, New Orleans, LA. 12 pp.

Johnson, R.L. 1979. A new method of storing Nuttall oak acorns over winter. U.S. Forest Service Tree Planters' Notes 30(2):6-8.

Johnson, R.L. 1983. Nuttall oakdirect seeding still successful after 11years. U.S. Forest Service Research Note SO-301, New Orleans, LA. 4 pp.

Kormanik, P.P., R.P. Belanger, and E.W. Belcher. 1976. Survival and growth of containerized and bareroot seedlings of cherrybark oak. U.S. Forest Service Tree Planters' Notes 27(3):9-10, 23.

Korstian, C.F. 1927. Factors controlling germination and early survival in oaks. Yale University School of Forestry Bulletin No. 19. Yale University, New Haven, CT. 115 pp. t plates.

Krinard, R.M., and J.K. Francis. 1983. Twenty-year results of planted cherrybark oak on old fields in brown loam bluffs. U.S. Forest Service Tree Planters' Notes 34(4):20-22.

Lotti, T. 1957. Silvical characteristics of cherrybark oak. U.S. Forest Service Southeastern Forest Experiment Station Paper 88. 9 pp.

McGee, C.E. 1978. Size and age of tree affect white oak sprouting. U.S. Forest Service Research Note SO-239, New Orleans, LA. 2 pp.

McKnight, J.S. 1958. Thinning stands of water oaks. Pages 46-50 in Proceedings of the seventh annual forest symposium; Louisiana State University, Baton Rouge.

McQuilkin, R.A., and R.A. Musbach. 1977. Pin oak acorn production on greentree reservoirs in southeastern Missouri. Journal of Wildlife Management 41:218-225.

Merz, R.W., and G.K. Barkhage. 1964. The management of pin oak in a duck shooting area. Journal of Wildlife Management 28:233-239.

Minckler, L.S., and D. Janes. 1965. Pin oak acorn production on normal and flooded areas. University of Missouri Agricultural Experiment Station Research Bulletin 898.

Minckler, L.S., and R.E. McDermott. 1960. Pin oak acorn production and regeneration as affected by stand density, structure and flooding. University of Missouri Research Bulletin 750, Columbia, MO.

Tuskan, G.A., and C.A. Blanche. 1980. Mechanical shaking improves Shumard oak germination. U.S. Forest Service Tree Planters' Notes 31(4):3-6.

SWEETGUM

Beaufait, W.R. 1957. Coppice regeneration of sweetgum. U.S. Forest Service Southern Forest Experiment Station Note 107, New Orleans, LA.

Broadfoot, W.M., and R.M. Krinard. 1959. Guide for evaluating sweetgum sites. U.S. Forest Service Southern Forest Experiment Station Occasional Paper 176, New Orleans, LA. 8 pp.

Brown, C.L., and R.B. McAlpine. 1964. Propagation of sweetgum from root cuttings. Georgia Forest Research Council Research Paper 24, Macon, GA.

Hu, S.C., P.E. Foggs, N.E. Linnartz, and P.Y. Borios. 1987. Sweetgum: a bibliography 1906-1986. Louisiana Agriculture Experiment Station Research Report 13. 77 pp.

Johnson, R.L. 1964. Coppice regeneration of sweetgum. Journal of Forestry 62:34-35.

Johnson, R.L. 1968. Thinning improves growth in stagnated sweetgum stands. U.S. Forest Service Research Note 82. 5 pp.

Kaszkurewicz, A., and T. Keister. 1975. Effects of intensive cultural treatments and seedling size on juvenile growth of sweetgum. U.S. Forest Service Tree Planters' Notes 26(3):5-8, 26.

Krinard, R.M., and R.L. Johnson. 1985. Eighteen-year development of sweetgum (Liauidambar strvaciflua L.) plantings on two sites. U.S. Forest Service Tree Planters' Notes 36(3):6-8.

Martindale, D.L. 1958. Silvical characteristics of sweetgum. U.S. Forest Service Southeastern Forest Experiment Station Paper 113.

Toole, E.R. 1954. Sweetgum blight--a problem in forest management. Southern Lumberman 189(2362):35.

Toole, E.R., and W.M. Broadfoot. 1959. Sweetgum blight as related to alluvial soils of the Mississippi River floodplain. Forest Science 5(1):2-9.

SYCAMORE

Briscoe, C.B. 1969. Establishment and early care of sycamore plantations. U.S. Forest Service Research Paper SO-50, New Orleans, LA. 18 pp.

Briscoe, C.B., and A.P. DuBarry, Jr. 1959. A simplified germination test for American sycamore. U.S. Forest Service Tree Planters' Notes 35:21.

Doolittle, W.T. 1956. Pruning sycamore. Southern Lumberman 193(2417):222-223.

Fitzgerald, C.H., R.F. Richards, C.W. Seldon, and J.T. May. 1975. Three-year effects of herbaceous weeds in a sycamore plantation. Weed Science 23(1):32-35.

Huppuch, C.D. 1960. The effect of site preparation on survival and growth of sycamore cuttings. U.S. Forest Service Research Note SE-140. 2 pp.

Ike, A.F., Jr. 1962. Root collar diameter is a good measure of height growth potential of sycamore seedlings. U.S. Forest Service Tree Planters' Notes 54:9-11.

Mertz, R.W. 1958. Silvical characteristics of American sycamore. U.S. Forest Service Central States Forest Experiment Station Miscellaneous Release 26. 20 pp.

McAlpine, R.B. 1963. A comparison of growth and survival between sycamore seedlings and cuttings. U.S. Forest Service Research Note SE-9. 1 pp.

Nelson, T.C., and D.L. Martindale. 1957. Rooting American sycamore cuttings. Journal of Forestry 55:532.

Sigafoos, R.S. 1976. Relations among surficial material, light, intensity, and sycamore seed germination along the Potomac River near Washington, D.C. U.S. Geological Survey Journal of Research 4:733-736.

Vande Linde, F. 1960. Nursery practice for growing sycamore seedlings. U.S. Forest Service Tree Planters' Notes 41:15-16.

Vande Linde, F. 1962. Collection and care of sycamore seed. U.S. Forest Service Tree Planters' Notes 54:22.

TUPELOS

Applequist, M.B. 1959. Soil site studies of southern hardwoods. Pages 49-63 in Proceedings of the eighth annual forest symposium; Louisiana State University, Baton Rouge, LA.

Applequist, M.B. 1959. A study of soil and site factors affecting the growth and development of swamp blackgum and tupelo gum stands in southeastern Georgia. Ph.D. Dissertation. Duke University, Durham, NC. 181 pp.

Bonner, F.T., and H.E. Kennedy, Jr. 1973. Storage of water tupelo seeds. U.S. Forest Service Tree Planters' Notes 24(4):7-8.

DeBell, D.S. 1971. Stump sprouting after harvest cutting on swamp tupelo. U.S. Forest Service Research Paper SE-83. 6 pp.

DeBell, D.S., and I.D. Auld. 1971. Establishment of swamp tupelo seedlings after regeneration cuts. U.S. Forest Service Research Note SE-164.

DeBell, D.S., and D.D. Hook. 1969. Seeding habits of swamp tupelo. U.S. Forest Service Research Paper SE-47. 8 pp.

DeBell, D.S., and A.W. Naylor. 1972. Some factors affecting germination of swamp tupelo seeds. Ecology 53(3):504-506.

Hadley, E.W. 1926. A preliminary study of the growth and yield of second-growth tupelo gum in the Atchafalaya basin of southern Louisiana. Lumber Trade Journal 90(10):17-18.

Harms, W.R. 1973. Some effects of soil type and water regime on growth of tupelo seedlings. Ecology 54:188-193.

Hook, D.D. 1968. Growth and development of swamp tupelo (*Nyssa sylvatica* var. *biflora*) under different root environments. Ph.D. Dissertation. Microfilm No. 69-9493. University of Georgia, Athens.

Hook, D.D., and D.S. DeBell. 1970. Factors influencing stump sprouting of swamp and water tupelo under various flooding conditions. Botanical Gazette 131:217-224.

Hook, D.D., W.P. LeGrande, and O.G. Langdon. 1967. Stump sprouts on water tupelo. Southern Lumberman 215(2680):111-112.

Hook, D.D., C.L. Brown, and P.P. Kormanik. 1970. Lenticel and water root development of swamp tupelo under various flooding conditions. Botanical Gazette 131:217-224.

Hook, D.D., O.G. Langdon, J. Stubbs, and C.L. Brown. 1970. Effect of water regimes on the survival, growth, and morphology of tupelo seedlings. Forest Science 16:304-311.

Hook, D.D., C.L. Brown, and P.P. Kormanik. 1971. Indicative flood tolerance in swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.). Journal of Experimental Botany 22(70):78-89.

Kennedy, H.E. 1969. Survival and first-year growth of water tupelo (*Nyssa aquatica* L.) in relation to flooding and siltation. Ph.D. Dissertation. Louisiana State University, Baton Rouge.

Kennedy, H.E. 1970. Growth of newly planted water tupelo seedlings after flooding and siltation. Forest Science 16:250-256.

Kennedy, H.E., Jr. 1982. Growth and survival of water tupelo coppice regeneration after six growing seasons. Southern Journal of Applied Forestry 6(3):133-135.

Kennedy, H.E., Jr. 1983. Water tupelo in the Atchafalaya basin does not benefit from thinning. U.S. Forest Service Research Note SO-298.

Klauwitter, R.A. 1964. Water tupelos like it wet. Southern Lumberman 209(2609):108-109.

Priester, D.S. 1979. Stump sprouts of swamp and water tupelo produce viable seeds. Southern Journal of Applied Forestry 3(4):149-151.

Shunk, I.V. 1939. Oxygen requirements for germination of seeds of *Nyssa aquatica*--tupelo gum. Science 90:565-566.

WILLOW

Beaufait, W.R. 1955. Soil profile observations relating to drought damage in black willow stands. Journal of Forestry 53(7):517.

Gill, C.J. 1974. Studies of radial stem growth in *Salix uinera* L. on a reservoir margin. Journal of Applied Ecology 11(1):215-221.

Johnson, R.L., and J.S. McKnight. 1969. Benefits from thinning black willow. U.S. Forest Service Research Note SO-89, New Orleans, LA. 6 pp.

Lamb, G.N. 1915. Willows: their growth, use, and importance. U.S. Department of Agriculture Bulletin 316, Washington, DC. 52 pp.

McKnight, J.S. 1957. Black willow--hints for management. Forests and People 7(3):30-31, 50.

McLeod, K.W., and J.K. McPherson. 1973. Factors limiting the distribution of *Salix nigra*. Torrey Botanical Club Bulletin 100(2):102-110.

YELLOW-POPLAR

Boyce, S.G., and J.F. Hosner. 1963. Alternating storage temperatures increase the germination of yellow-poplar seed. Journal of Forestry 61(10):731-733.

Boyce, S.G., and R.E. Parry. 1958. Effects of seedbed conditions on yellow-poplar regeneration. Journal of Forestry 56(10):751-753.

Carvell, K.L. 1966. Underplanting: a method of replacing unproductive hardwood stands with yellow-poplar. West Virginia Agricultural Experiment Station Bulletin 523:3-4.

Carvell, K.L., and C.F. Korstian. 1955. Production and dissemination of yellow-poplar seed. Journal of Forestry 53:169-170.

Clark, F.B. 1958. Direct seeding yellow-poplar. Journal of Forestry 56(5):351.

Clark, F.B. 1964. Micro-organisms and soil structure affect yellow-poplar growth. U.S. Forest Service Research Paper CS-9. 12 pp.

Clark, F.B., and S.G. Boyce. 1964. Yellow-poplar seed remains viable in the forest litter. Journal of Forestry 62(8):564-567.

Engle, L.G. 1960. Yellow-poplar seedfall pattern. U.S. Forest Service Central States Forest Experiment Station Note 143. 2 pp.

Enright, L.J. 1957. Vegetative propagation of Liriodenchon tulipifera. Journal of Forestry 55:892-893.

Freese, F. 1952. Yellow-poplar underplanting. U.S. Forest Service Southern Forest Experiment Station Notes 77.

Funk, D.T. 1958. Frost damage to yellow-poplar varies by seed source and site. U.S. Forest Service Central States Forest Experiment Station Note 115. 2 pp.

Green, A.W., and D.J. Neebe. 1957. Early development of yellow-poplar on two planting sites. U.S. Forest Service Central States Forest Experiment Station Note 106. 2 pp.

Guard, A.T., and R.E. Wean. 1941. Seed production in the tulip poplar. Journal of Forestry 39:1032-1033.

Hinson, E. 1935. Collection of yellow-poplar seed. Journal of Forestry 33:1007-1008.

Ike, A.F., Jr. 1962. Fertilized yellow-poplar seedings maintain growth advantage after four years. U.S. Forest Service Southeastern Forest Experiment Station Research Note 175. 2 pp.

Johnson, R.L., and R.M. Krinard. 1963. Planted yellow-poplar outperforms six other species on loess sites. U.S. Forest Service Tree Planters' Notes 61:11-12.

Limstrom, G.A. 1959. Yellow-poplar seed quality varies by seed trees, stands and years. U.S. Forest Service Central States Forest Experiment Station Note 134.

Limstrom, G.A., and R.F. Finn. 1956. Seed source and nursery effects on yellow-poplar plantations. Journal of Forestry 54:828-831.

Limstrom, G.A., R.F. Finn, and G.M. Deitschmann. 1953. How to grade yellow-poplar planting stock. U.S. Forest Service Central States Forest Experiment Station Note 81. 2 pp.

Lotti, T. 1955. Yellow-poplar height growth affected by seed source. U.S. Forest Service Tree Planters' Notes 22:3.

Luxmoore, R.J., D.D. Huff, R.K. McConathy, and B.E. Dinger. 1978. Some measured and simulated plant water relations of yellow-poplar. Forest Science 24(3):327-341.

McAlpine, R.G. 1959. Response of yellow-poplar to. diammonium phosphate fertilizer. U.S. Forest Service Southeastern Forest Experiment Station Note 132. 2 pp.

McAlpine, R.G. 1959. Flooding kills yellow-poplar. Forest Farmer 19(3):9, 13, 14.

McAlpine, R.G. 1961. Yellow-poplar seedlings intolerant to flooding. Journal of Forestry 59:566-568.

McAlpine, R.G. 1964. A method for producing clones of yellow-poplar. Journal of Forestry 62(2):115-116.

McCarthy, E.F. 1933. Yellow-poplar characteristics, growth, and management. U.S. Department of Agriculture Bulletin 356. 58 pp.

McGee, C.E. 1977. Planted yellow-poplar grows well after essential site preparation. U.S. Forest Service Tree Planters' Notes 28(1):5-7, 38.

Merz, R. 1951. Comparative survivals and costs of plantations by different methods of ground preparation and planting. U.S. Forest Service Central States Forest Experiment Station Note 64. 2 pp.

Merz, R., and R.F. Finn. 1955. Yellow-poplar responds to pre-planting ground treatment. U.S. Forest Service Central States Forest Experiment Station Technical Paper 105. 18 pp.

Munn, L.C., and J.P. Vimmerstedt. 1980. Predicting height growth of yellow-poplar from soils and topography in southeastern Ohio. Soil Science Society of America Journal 44(2):384-387.

Nelson, T.C., and L.W. Jackson. 1956. Yellow-poplar plantations. Forest Farmer 15(10):11.

Nelson, T.C. 1957. A method of vegetatively propagating yellow-poplar. Journal of Forestry 55:589.

Paton, R.R. 1945. Storage of tuliptree seed. Journal of Forestry 43:764-765.

Phillips, J.J. 1962. Some effects of competition on the survival of yellow-poplar seedlings. U.S. Forest Service Research Note NE-134. 4 pp.

Schoenike, R.E. 1980. Yellow poplar (*Liriodendron tulipifera* L.): an annotated bibliography to and including 1974. Clemson University, S.C. 700 pp.

Schomaker, C.E. 1958. Two year results of planting yellow-poplar in North Alabama. Journal of Forestry 56:37-38.

Shipman, R.D. 1953. A silvical study of certain factors contributing to the differential height growth of plantation-grown tulip poplar (*Liriodendron tulioifera*). Journal of Forestry 51:128-129.

Stephens, G.R., Jr. 1965. Yellow-poplar seedlings respond to soil temperature. Journal of Forestry 63:701-703.

Tryon, E.H., and K.L. Carvell. 1960. Environmental factors affecting yellow-poplar survival under a young stand. Castanea 25(2):69-73.

Tulli, A.R. 1962. Investigations on top-pruning, method of planting, and site preparation for yellow-poplar (Liriodendron tulipifera). M.S. Thesis. North Carolina State University at Raleigh.

Wean, R.E., and A.T. Guard. 1940. The viability and collection of seed of Liriodendron tulioifera. Journal of Forestry 38:815-817.

MISCELLANEOUSSPECIES

Aird, P.F. 1962. Fertilization, weed control, and growth of poplar. Forest Science 8(4):413-428.

Barnett, J.P. 1979. Storing spruce pine seeds. U.S. Forest Service Tree Planters' Notes 30(4):20-21.

Bonner, F.T. 1975. Maturation of black cherry fruits in central Mississippi. U.S. Forest Service Research Note SO-205, New Orleans, LA. 4 pp.

Davidson, W.H. 1976. Birch species survive well on problem coal mine spoils. Pages 26-29 in Proceedings of the 24th northeastern forest tree improvement-conference.

Fletcher, W.F. 1942. The native persimmon. U.S. Department of Agriculture Farmers' Bulletin 685. 22 pp.

Funk, D.T. 1957. Silvical characteristics of honey locust. U.S. Forest Service Central States Forest Experiment Station Miscellaneous Release 23.

Gomes, A.R.S., and T.T. Kozlowski. 1980. Growth responses and adaptations of Fraxinus pennsvlvanica seedlings to flooding. Plant Physiology 66:267-271.

Guilkey, P.C. 1957. Silvical characteristics of American elm. U.S. Forest Service Lake States Forest Experiment Station Paper 54.

Kennedy, H.E., Jr. 1972. Horizontal planting of green ash cutting looks promising. U.S. Forest Service Research Note SO-147, New Orleans, LA. 3 pp.

Kennedy, H.E., Jr. 1974. Horizontal planting of green ash cuttings on a Sharkey clay site. Pages 7-11 in Proceedings of the southeastern area nurserymens' conference.

Kennedy, H.E., Jr. 1977. Planting depth and source affect survival of planted green ash cuttings. U.S. Forest Service Research Note SO-224, New Orleans, LA. 3 pp.

Miller, M.A. 1983. A study of forested wetland ecosystems influenced by the phosphate industry. Pages 190-222 in D.J. Robertson, ed. Reclamation and the phosphate industry. Proceedings of the symposium; Clearwater Beach, FL; 26-28 January 1983. Florida Institute of Phosphate Research, Bartow.

Norby, R.J., and T.T. Kozlowski. 1983. Flooding and SO_2 stress interaction in *Betula papyrifera* and *B. nigra* seedlings. Forest Science 29(4):739-750.

Skallerup, H.R. 1953. The distribution of *Diospyros virginiana*. Annals of the Missouri Botanical Garden 40(3):211-225.

Sparks, R.C., and J.R. Toliver. 1978. Performance of three-year-old open-pollinated progeny of 40 selected native pecan trees. Louisiana State University Forestry Note No. 124, Baton Rouge.

Steinbauer, G.P. 1937. Dormancy and germination of *Fraxinus* seeds. Plant Physiology 12:813-814.

Sterrett, W.D. 1915. The ashes: their characteristics and management. U.S. Department of Agriculture Bulletin 299. 88 pp.

Stoutemyer, V.T., F.L. O'Rourke, and W.W. Steiner. 1944. Some observa-observations on the vegetative propagation of honeylocust. Journal of Forestry 42:32-36.

Toliver, J.R. 1979. Planting pecan for timber production and other benefits may be a worthwhile project on your land. Hardwood Hardfacts. Louisiana Cooperative Extension Service, Baton Rouge.

Toliver, J.R. 1983. Comparison of pecan, water hickory, and their hybrids. Louisiana Agricultural Experiment Station Bulletin 26(4):4-5.

Toliver, J.R. 1983. Size of nursery stock affects pecan seedling performance after three years of growth in the field. Louisiana State University Forestry Note No. 139, Baton Rouge, LA.

Toliver, J.R., and J.E. Hotvedt. 1983. Growth and development of a 20-year-old unthinned spruce pine plantation. Pages 288-290 *in* E.P. Jones, ed. Second biennial southern silvicultural research conference, Atlanta, GA. U.S. Forest Service General Technical Report SE-24, Asheville, NC.

Waring, H.D. 1961. The soil requirements of poplars. Australian Forestry 25:89-91.

Wenger, K.F., editor. 1984. Forestry handbook (2nd ed.). John Wiley and Sons, New York. 1,335 pp.

Woessner, R.A., and V. Hicks, Jr. 1973. Three-year height of green ash not affected by root and top pruning. U.S. Forest Service Tree Planters' Notes 24(4):13-14.

Wolfe, C.B., and J.D. Pittillo. 1977. Some ecological factors influencing the distribution of _Betula nigra_ L. in western North Carolina. Castanea 42:18-30.

Wright, J.W. 1959. Silvical characteristics of the green ash. U.S. Forest Service Northeastern Forest Experiment Station Paper 126.

Appendix A. Common and scientific names for some bottomland forest species (from Clark and Benforado 1981).

Common name	Scientific name
Carolina ash	*Fraxinus caroliniana*
Pumpkin ash	*F. profunda*
Green ash	*F. pennsvlvanica*
White ash	*F. americana*
American beech	*Fagus grandifolia*
River birch	*Betula niqra*
Buttonbush	*Cephalanthus occidentalis*
Black cherry	*Prunus serotina*
Eastern cottonwood	*Populus deltoides*
Swamp cottonwood	*P. heterophylla*
Baldcypress	*Taxodium distichum*
Pondcypress	*T. distichum* var~~. nutans~~
Flowering dogwood	*Cornus florida*
Rough-leaf dogwood	*C. drummondii*
American elm	*Ulmus americana*
Cedar elm	*U. crassifolia*
Slippery elm	*U. rubra*
Winged elm	*U. alata*
Water-elm	*Planera aauatica*
Sweetgum	*Liauidambar stvraciflua*
Blackgum	*Nyssa sylvatica*
Ogeechee tupelo	*N. oqeche*
Swamp tupelo	*N. svlvatica* var. *biflora*
Water tupelo	*N. aauatica*
Hackberry	*Celtis occidentalis*
Sugarberry	*C. laevioata*
Hawthorn	*Crataequs* spp.
Water hickory	*Carva aauatica*
Shellbark hickory	*C. laciniosa*
Shagbark hickory	*C. ovata*
Pecan	*C. illinoensis*
American holly	*Ilex opaca*
Possumhaw	*I. decidua*
Eastern hophornbeam	*Ostrva virqiniana*
American hornbeam	*Carpinus caroliniana*
Honeylocust	*Gleditsia triacanthos*
Waterlocust	*G. aauatica*
Loblolly-bay	*Gordonia lasianthus*
Redbay	*Persea borbonia*
Southern magnolia	*Maqnolia srandiflora*
Swampbay	*Persea borbonia* var. *pubescens*
Sweetbay	*Masnolia viroin*iana

(Continued)

Appendix A. (Concluded).

Common name	Scientific name
Boxelder	Acer nectundo
Florida maple	A. barbatum
Red maple	A. rubrum
Silver maple	A. saccharinurn
Red mulberry	Morus rubra
Bur oak	Quercus macrocarpa
Cherrybark oak	Q. falcata var. Daqodifolia
Delta post oak	Q. stellata var. paludosa
Laurel oak	Q. laurifolia
Live oak	Q. viroiniana
Nuttall oak	Q. nuttallii
Overcup oak	Q. lyrata
Pin oak	Q. palustris
Shumard oak	Q. shumardii
Swamp chestnut oak	Q. michauxii
Water oak	Q. niqra
White oak	Q. alba
Swamp white oak	Q. bicolor
Willow oak	Q. phellos
Pawpaw	Asimina triloba
Common persimmon	Diosovros viroiniana
Sassafras	Sassafras albidum
American sycamore	Plantanus occidentalis
Swamp-privet	Forestiera acuminata
Black walnut	Juolans nisra
Black willow	Salix niqra
Sandbar willow	S. exiqua
Yellow-poplar	Liriodendron tulipifera

Appendix B. Table of flooding and shade tolerance and reproductive characteristics of some bottomland forest species (from Fowells 1965; McKnight et al. 1981).

KEY TO FLOOD TOLERANCE

T (tolerant)--Species are able to survive and grow on sites where soil is saturated or flooded for long periods during the growing season. Species have special adaptations for flood tolerance.

MT (moderately tolerant)--Species are able to survive saturated or flooded soils for several months during the growing season but mortality is high if flooding persists or reoccurs for several consecutive years. These species may develop some adaptations for flood tolerance.

WT (weakly tolerant)--Species are able to survive saturated or flooded soils for relatively short periods of a few days to a few weeks during the growing season; mortality is high if flooding persists longer. Species do not appear to have special adaptations for flood tolerance.

I (intolerant)--Species are not able to survive even short periods of soil saturation or flooding during the growing season. Species do not show special adaptations for flood tolerance.

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Carolina ash	T--Seeds remain viable in water for months.	Intermediate. Seedlings moderately tolerant.	Seeds dispersed Oct.-Feb. by wind and water. Seedlings establish on bare, moist soil after water recedes. Sprouts well from stumps.
Pumpkin ash	Same as for Carolina ash.	Same as for Carolina ash.	Same as for Carolina ash.
Green ash	MT	Same as for Carolina ash.	Seeds dispersed from fall to early spring primarily by wind and to some extent by water. Germination on bare, moist soil in openings. Sprouts prolifically. Excellent seed dispersal.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
White ash	WT	Same as for Carolina ash.	Seeds dispersed Sept.-Jan. primarily by wind. Seedlings establish best on bare, moist, well-drained soils. Sprouts prolifically from stumps.
American beech	I	Very tolerant	Seedfall Sept.-Dec. by gravity and animals to some extent. Trees about 40 years of age (optimum 60 years) bear seed. Dispersal usually limited to crown area. Seedlings establish best in shade on moist, well-drained soils. Sprouts well from roots and stumps.
River birch	MT	Intolerant	Seeds dispersed May-June by wind and water. Trees bear seed at about 40 years of age. Seedlings establish on moist, well-drained soils. Rapid early growth from seed.
Buttonbush		Tolerant	Seeds dispersed Oct.-Nov. by wind and water. Very moist seedbed is optimum. Stumps of all sizes sprout.
Black cherry		Intermediate	Seeds dispersed Aug.-Nov. Birds and animals may move seeds long distances. Trees from about 10 to 180 years of age bear seed. Seeds establish in bare mineral soil or in leaf litter. Sprouts from stumps.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Eastern cottonwood	WT-MT	Very intolerant	Seeds dispersed May-Aug. largely by wind and water. Trees as early as 10 years of age (optimum 30-40 years) bear seed. Seeds may remain viable for less then 2 weeks. Germination best on moist mineral soil. Sprouts well from stumps. up to 12 inches.
Swamp cottonwood	MT	Intermediate	Seeds dispersed April-July largely by wind and somewhat by water. Trees about 10 years of age bear seed. Seeds short-lived. Germination best on bare, moist, mineral soil. Rapid early growth. Sprouts well from stumps up to 12 inches.
Baldcypress	T--seeds stay viable in water up to 30 months Prolonged submergence of seedlings is fatal.	Intermediate	Seeds dispersed Nov.-Feb. primarily by water. Seedlings established when water recedes. Sprouting inconsistent from stumps up to 20 inches.
Pondcypress	T	Intermediate	Similar to baldcypress.
Flowering dogwood	I	Very tolerant	Seeds dispersed Nov. by gravity, animals, and birds. Germination best on bare mineral soil in understory or openings. Stumps of all sizes sprout well.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Rough-leaf dogwood	T	Tolerant	Seeds dispersed in fall by gravity, animals, and birds. Seedlings establish best on moist soil under partial shade. Sprouts well from stumps.
American elm	MT-Seeds remain viable when submerged for a month.	Tolerant	Seeds dispersed March-June by wind and water. Trees as early as 15 years of age bear seed. Seeds germinate and seedlings establish on surface of moist mineral soil or on undisturbed humus. Stumps up to 15 inches sprout well.
Cedar elm	MT	Tolerant	Seeds dispersed Oct.-Nov. largely by wind and water. Seedlings established in shade or in openings on moist, bare mineral soil. Stumps up to 12 inches sprout well.
Slippery elm	I	Tolerant	Seeds dispersed April-June largely by wind and less by water. Trees as early as 15 years of age, (optimum 25-125 years) bear seed. Seedlings established in shade or in openings on moist, usually well-drained soil. Stumps up to 12 inches sprout well.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Winged elm	WT-I	Tolerant	Seeds dispersed in April by wind and water. Seedlings largely in new openings. Stumps to 12 inches sprout well.
Water elm		Tolerant	Seeds dispersed in April. Seedlings established after water recedes. Sprouts well from stumps.
Sweetgum	MT	Intolerant--cannot stand over-topping.	Seeds dispersed in fall primarily by wind. Trees about 20 years of age, continuing to 150 or more years, bear seed. Prolific seeder. Germination best on mineral soil in open. Sprouts well from roots and stumps.
Blackgum	WT	Intermediate	Seeds dispersed Sept.-Nov. by water and to some extent by animals. Germination and establishment only on dry soil. Stumps to 12 inches sprout well.
Ogeechee tupelo	T--Seeds can survive in water for several months.	Intolerant	Seeds dispersed Oct.-Nov. Birds and animals may move some seed. Seedlings produced when water recedes.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Swamp tupelo	T--Seeds remain viable for months in water	Intermediate--does not tolerate overtopping. Responds to release.	Seeds dispersed primarily by birds and somewhat by water. Trees bear seed at about 30 years of age. Usually good-to-excellent seed crop. Germinates best in partial shade on moist seedbed. Sprouts from stumps and sprouts produce viable seeds in second year.
Water tupelo	T--Seeds remain viable for months in water.	Intolerant	Seeds dispersed by water and animals. Trees beginning about 30 years of age bear seed. Usually good-to-excellent seed crop. Needs full sunlight for germination. Stump sprouts produce viable seeds in second year.
Hackberry and Sugarberry	MT--Seeds remain viable for months in water; seedlings cannot tolerate submergence.	Very tolerant	Seeds dispersed Oct.-Jan. by birds, animals, and water. Trees at about 15 years of age (optimum 30-70 years) bear seed. Seedlings often in full shade. Sprouts well from stumps to 12 inches.
Hawthorn	MT	Intermediate to intolerant	Seeds dispersed fall and winter. Does not readily establish seedlings. Trees are good sprouters.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Water hickory	MT--Seeds remain viable in water for several months.	Intermediate	Seeds dispersed Oct.-Dec. by gravity, water, animals, and birds. Trees at about 20 years of age (optimum 40-75 years) bear seed. Seedlings more common in new openings but also occur in understory. Sprouts well from stumps to 20 inches.
Shellbark hickory	WT	Very tolerant	Seeds dispersed Oct.-Dec. by gravity, animals, and birds. Trees at about 40 years of age (optimum 75-200 years) bear seed. Germination and establishment in understory and openings. Moist soils are required for seedling establishment. Sprouts well from stumps.
Shagbark hickory	WT	Moderately tolerant	Seeds dispersed Sept.-Dec. by gravity and animals. Trees at 40 years of age (optimum 60-200 years) bear seed. Seedlings require moderately moist seedbed. Sprouts well from stumps.
Pecan	WT	Intolerant	Seeds dispersed Sept.-Dec. by birds and animals. Trees at about 20 years of age (optimum 75-225 years) bear seed. Seedlings establish best in an inch or so under loamy soil. Sprouts well from stumps to 12 inches.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
American holly	WT	Very tolerant	Seeds dispersed Nov.-March by birds and animals. Seedlings occur in understory and openings. Sprouts well from stumps.
Possumhaw	MT	Very tolerant	Seeds dispersed Sept.-March. Seedlings become established in shade and openings. Sprouts well from stumps.
Eastern hophornbeam	I	Very tolerant	Seeds dispersed in fall. Seedlings establish well in understory and new openings. Moist mineral soil is best seedbed. Sprouts well from stumps of all sizes.
American hornbeam	MT	Very tolerant	Seeds dispersed fall to spring largely by birds and short distances by wind. Similar to Eastern hophornbeam.
Honeylocust	MT	Intolerant	Seeds dispersed Sept.-Feb. by wind, birds, animals, and sometimes water. Trees at about 10 years of age (optimum 25-75 years) bear seed. New seedlings seldom in understory, but in openings. Sprouts well from stumps.
Waterlocust	MT	Intolerant	Similar to honeylocust.
Loblolly-bay	MT	Intermediate	Seeds dispersed in fall.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Redbay	MT	Tolerant	Seeds dispersed in fall to some extent by birds. Germinates in both understory and openings. Fire stimulates germination. Sprouts well from stumps.
Southern magnolia	WT	Tolerant	Seeds dispersed Sept.-Dec. by birds and other animals. Trees as early as 10 years of age bear seed. Usually good seed crop, but low germination. Good stump sprouter.
Swamp bay	MT	Tolerant	Seeds dispersed in fall by birds. Seedlings establish both in understory and openings. Good stump sprouter.
Sweetbay	MT	Moderately tolerant	Seeds dispersed Sept.-Nov. by birds and small animals. Seedlings establish both in shade and openings.
Boxelder	MT	Moderately tolerant	Seeds dispersed Sept.-March by wind, birds, and small animals. Germinates best on moist mineral soil in shade or openings. Sprouts well from stumps.
Florida maple	WT	Tolerant	Seeds dispersed Oct.-Dec. by wind, birds, and small animals. Germinates best on moist mineral soil in shade or openings. Sprouts well from stumps.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Red maple	MT	Tolerant	Seeds dispersed March-July primarily by winds, and to some extent, by water, birds, and small animals. Germinates best on moist mineral soil in shade or openings, often after water recedes. Sprouts well from stumps.
Silver maple	MT	Moderately tolerant to intolerant	Seeds dispersed April-June by wind, water, birds, and small animals. Trees about 35-40 years of age (or sooner if grown in the open) bear seed. Seedlings occur in shade or openings. Sprouts well from stumps.
Red mulberry	WT-I	Very tolerant	Seeds dispersed June-Aug. by birds and other animals. Seedlings occur in shade or openings. Sprouts well from stumps.
Bur oak		Intermediate	Seeds dispersed Aug.-Nov. mainly by gravity and squirrels, and to a limited extent by water. Trees at about 35 years of age (optimum 75-150 years) bear seed. Germination may be prolific in bottomland areas; seedlings are often killed if flooded during the growing season. Sprouts well from stumps and following burning of small trees although the quality and form of sprout stems often poor.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Cherrybark oak	WT-I	Moderately intolerant to intolerant	Seed dispersed Aug.-Nov. by gravity, birds, and animals; seldom by water. Trees seed at about 25 years of age (optimum 50-75 years). Not a good stump sprouter.
Delta post oak	WT-I	Intermediate	Seeds dispersed in fall by gravity, birds, animals, and sometimes water. Trees bear seed at about 25 years of age. Seedlings most common in openings. Not a good stump sprouter.
Laurel oak	MT-WT	Intermediate to tolerant	Seeds dispersed Sept.-Dec. by gravity, birds, animals, and sometimes water. Trees begin to bear seed at about 15-20 years of age. Seedlings in shade or openings. Sprouts when cut or burned.
Live oak	WT-T	Intolerant	Seeds dispersed Sept.-Nov. by gravity, birds, and animals. Germinates best in moist warm soil. Sprouts well from roots.
Nuttall oak	MT--acorns remain viable in water for at least 34 days. Seedlings killed by flooding during growing season.	Intolerant	Seeds dispersed Sept.-Feb. by animals and water. Germination best in moist soil covered with leaf litter. Trees may bear seed as early as 5 years of age. Seedlings establish in shade. Stumps of young trees sprout readily.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Overcup oak	MT--Seedlings among most tolerant of the oaks, but may be killed by high water during first growing seasons.	Moderately intolerant	Seeds dispersed Sept.-Nov. by birds, animals, and water. Trees bear seed at about 25 years of age. Acorns viable after 4 months in water. Germination best on moist mineral soil. Sprouting from small stumps only.
Pin oak	MT--Seedlings among most tolerant of the oaks.	Intolerant	Seeds dispersed Sept.-Dec. by birds and small animals, gravity, and to some extent by water and wind. Trees bear seed between ages of 25 and 80 years, although trees in openings often produce seed by 15 years. Seedlings become established in understory openings, but many seedlings killed by flooding during growing season. Sprouts well from stumps of small trees.
Shumard oak	WT	Intolerant	Seeds dispersed Sept.-Dec. by gravity and animals; seldom by water. Trees bear seed at about 25 years of age (optimum at 50 years). Seedling establishment best in openings. Sprouting best from stumps of young trees; a poor sprouter overall.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Swamp chestnut oak	WT--Seedlings are intolerant to flooding.	Moderately tolerant	Seeds dispersed Sept.-Oct. by gravity and animals. Seed bearing begins about 25 years of age (optimum at about 40 years). Germination best on moist, well-drained soils with a light cover of leaves. Seedlings require full sunlight for best development. Sprouts from small stumps.
Water oak	WT-MT--Prolonged submergence of seedlings during growing season is fatal.	Intolerant	Seeds dispersed Sept.-Nov. by gravity, birds, animals, and water. Seed production begins at about 20 years of age. Seedlings establish best on moist, well-aerated soil under light leaf litter. Sprouts readily from young stumps.
White oak	I-WT--Seedlings intolerant.	Intermediate	Seeds dispersed Sept.-Nov. by gravity and squirrels. Seed bearing normally between 50 and 200 years for open-grown trees. Germination best on moist, well-drained soil. Sprouts well from stumps and following fire damage.
Swamp white oak	MT	Intermediate	Seeds dispersed primarily by gravity, rodents, and water. Trees about 35 years of age (optimum 75-200 years) bear seed. Sprouts from stumps.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Willow oak	WT-MT--Prolonged flooding during growing season is fatal.	Intolerant	Seeds dispersed Oct.-Dec. by gravity, animals and water. Trees bear seed at about 20 years of age. Germination best on moist, well-aerated soil with light leaf litter. Sprouts from young stumps.
Pawpaw		Very tolerant	Seeds dispersed Aug.-Oct. by gravity, birds, and small animals. Seedlings establish in shade and openings. Sprouts well from stumps.
Persimmon	MT--Prolonged flooding or submergence by water during growing season will kill young trees.	Tolerant	Seeds dispersed Oct.-Dec. by animals and birds. Trees bear seed as early as 10 years of age (optimum 25-50 years). Seedlings establish in understory and openings. Sprouts readily from stumps and roots.
Sassafras		Intolerant	Seeds dispersed Sept.-Oct. by gravity and birds. Trees about 10 years of age (optimum 25-50 years) bear seed. Germination best on moist loamy soil with litter. Grows well in openings. Sprouts well from roots and stumps.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Sycamore	MT--Seeds remain viable in water for 1 month. Seedlings cannot tolerate prolonged flooding.	Moderately tolerant	Seeds dispersed Jan.-April by wind, water, and birds to some extent. Trees 25 years of age (optimum 50-200 years) bear seed. Seedlings establish best on moist mudflats or other exposed mineral soil. Sprouts well from stumps.
Swamp-privet	T--Viability of seed not reduced by prolonged submergence in water.	Tolerant	Seeds dispersed June-July by water and birds. Germination best in moist mineral soil. Sprouts well from stumps.
Black walnut	WT--Seedlings intolerant.	Intolerant	Seeds dispersed Oct.-Nov. by gravity and animals. Trees may bear seed at 8 years of age (optimum 30-100 years). Seedlings mainly in forest openings. Small stumps sprout well.
Black willow	T--Seeds will germinate in water.	Very intolerant	Seeds dispersed April-July by wind and water. Trees about 10 years of age (optimum 25-75 years) bear seed. Germination best on very moist, exposed mineral soil. Sprouts well from stumps of small trees.
Sandbar willow	MT--Seedlings tolerate well.	Very intolerant	Seeds dispersed April-May by wind and water. Similar to Black willow.

(Continued)

Appendix B. (Continued).

Common name	Flood tolerance	Shade tolerance	Reproductive characteristics
Yellow-poplar	I--Seedlings cannot tolerate flooding.	Intolerant	Seeds dispersed Oct.-March by wind. Trees bear seed at about 15-20 years of age and continue to 200 years or more. Seedlings establish best on moist seedbeds of mineral soil and survive only in full sunlight. Sprouts readily from stumps.

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  Johnson 1981a
  Johnson 1983
  Johnson and Krinard 1985a
  Krinard and Johnson 1976
  Krinard and Kennedy 1981
  Krinard and Kennedy 1983
  Krinard and Kennedy 1987

Urbo
  Francis 1985

Wartrace
  Gilmore and Boggess 1963

Wymore silty loam
  Loucks and Keen 1973

South Carolina
  Klawitter 1963
  Sharitz and Lee 1985
  Stubbs 1963a
  Stubbs 1963b

Survival and growth
  Anderson et al. 1983
  Anonymous 1984
  Ashby et al. 1980
  Baker 1977
  Bates et al. 1978
  Bonner 1966
  Briscoe 1957
  Briscoe 1963
  Broadfoot and Krinard 1961
  Conner 1988
  Finn 1958
  Fung 1986
  Gilbert et al. 1981
  Gilmore and Boggess 1963
  Hansen and McComb 1955
  Harris et al. 1985
  Hosner 1959
  Hosner and Boyce 1962
  Johnson 1983
  Johnson and Krinard 1985a
  Johnson and Krinard 1985b
  Johnson and Krinard 1987
  Johnson and Price 1959
  Kennedy 1984
  Kennedy and Krinard 1985
  Kennedy et al. 1986
  Krinard and Johnson 1976
  Krinard and Kennedy 1981
  Krinard and Kennedy 1983
  Krinard and Kennedy 1987
  Maisenhelder and Heavrin 1957
  Maki et al. 1980
  Moore 1950
  Nawrot and Yaich 1983
  Nelson 1957
  Philo 1982
  Richards et al. 1982
  Robertson [1985]
  Stubbs 1963a
  Stubbs 1963b
  Toliver 1986
  Vogel 1973
  Vogel 1980
  Wadsworth 1983
  Waldrop et al. 1983

Tennessee
  Broadfoot and Krinard 1961
  Waldrop et al. 1983

Texas
  Howells 1986

Virginia
  Malac and Heeren 1979

Weed Control
  Bonner 1964
  Clewell 1983
  Gilmore and Boggess 1963
  Johnson 1979
  Johnson and Biesterfeldt 1970
  Johnson and Krinard 1985b
  Kennedy 1984
  Kennedy and Krinard 1985
  Krinard and Kennedy 1981
  Krinard and Kennedy 1983
  Krinard and Kennedy 1987
  Maisenhelder and Heavrin 1957
  Malac and Heeren 1979
  Schrand and Holt 1983
  Seifert et al. 1985
  Toliver 1986
  Waldrop et al. 1983

West Virginia
  Rafaill and Vogel 1978

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This bibliography was prepared to assist environmental planners, managers, and others who are interested in reestablishing bottomland hardwood forests on disturbed sites. Emphasis is on the Southeastern United States. There are 111 annotated entries; 259 non-annotated entries; and two appendixes--(A) common and scientific names and (B) flooding and shade tolerances and reproductive characteristics of common bottomland hardwood forest species. Cross-referencing is by species and subject.

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