PRACTICE AND PERSPECTIVE

Recognizing and Overcoming Difficult Site Conditions for Afforestation of Bottomland Hardwoods

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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than direct-seeding acorns, only 23 percent of the land planted with seedlings met the criteria (C.J. Schweitzer unpublished data).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*)	water tupelo (*Nyssa aquatica*)
Carolina ash (*Fraxinus caroliniana*)	water-elm (*Planera aquatica*)
pumpkin ash (*Fraxinus profunda*)	black willow (*Salix nigra*)
swamp-privet (*Forestiera acuminata*)	baldcypress (*Taxodium distichum*)
swamp tupelo (*Nyssa sylvatica* var. *biflora*)	pondcypress (*Taxodium distichum* var. *nutans*)
Highly Tolerant	
water hickory (*Carya aquatica*)	overcup oak (*Quercus lyrata*)
waterlocust (*Gleditsia aquatica*)	
Moderately Tolerant	
boxelder (*Acer negundo*)	sweetgum (*Liquidambar styraciflua*)
red maple (*Acer rubrum*)	sweetbay (*Magnolia virginiana*)
silver maple (*Acer saccharinum*)	water oak (*Quercus nigra*)
river birch (*Betula nigra*)	pin oak (*Quercus palustris*)
hawthorn (*Crataegus* spp.)	willow oak (*Quercus phellos*)
common persimmon (*Diospyros virginiana*)	Nuttall oak (*Quercus nuttallii*)
green ash (*Fraxinus pennsylvanica*)	sycamore (*Platanus occidentalis*)
honeylocust (*Gleditsia triacanthos*)	eastern cottonwood (*Populus deltoides*)
deciduous holly (*Ilex decidua*)	cedar elm (*Ulmus crassifolia*)
Weakly Tolerant	
American hornbeam (*Carpinus caroliniana*)	blackgum (*Nyssa sylvatica*)
pecan (*Carya illinoensis*)	cherrybark oak (*Quercus falcata* var. *pagodaefolia*)
shellbark hickory (*Carya laciniosa*)	laurel oak (*Quercus hemisphaerica*)
sugarberry (*Celtis laevigata*)	swamp chestnut oak (*Quercus michauxii*)
hackberry (*Celtis occidentalis*)	Shumard oak (*Quercus shumardii*)
American holly (*Ilex opaca*)	live oak (*Quercus virginiana*)
black walnut (*Juglans nigra*)	winged elm (*Ulmus alata*)
red mulberry (*Morus rubra*)	
Least Tolerant	
pawpaw (*Asimina triloba*)	black cherry (*Prunus serotina*)
flowering dogwood (*Cornus florida*)	white oak (*Quercus alba*)
American beech (*Fagus grandifolia*)	sassafras (*Sassafras albidum*)
yellow-poplar (*Liriodendron tulipifera*)	slippery elm (*Ulmus rubra*)
eastern hophornbeam (*Ostrya virginiana*)	

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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