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Restoration of bottomland hardwood forests across a treatment intensity gradient

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ABSTRACT

Large-scale restoration of bottomland hardwood forests in the Lower Mississippi Alluvial Valley (USA) under federal incentive programs, begun in the 1990s, initially achieved mixed results. We report here on a comparison of four restoration techniques in terms of survival, accretion of vertical structure, and woody species diversity. The range of treatment intensity allowed us to compare native recolonization to direct seeding and planting of *Quercus nuttallii* Palmer, and to an intensive treatment of interplanting two species that differed in successional status (early successional *Populus deltoides* Bartram ex Marsh. ssp. *deltoides*, with the mid-successional *Q. nuttallii*). Native recolonization varied in effectiveness by block but overall provided few woody plants. All active restoration methods (planting and direct seeding) were successful in terms of stocking. *Populus* grew larger than *Quercus*, reaching canopy closure after 2 years and heights after 2 and 5 years of 6 and 12.7 m, respectively. Planted *Quercus* were significantly larger than direct seeded *Quercus* in all years, but only averaged 1.4 m in height after 5 years. Interplanting did not seem to facilitate development of the *Quercus* seedlings. The early success of the interplanting technique demonstrated that environmental benefits can be obtained quickly by more intensive efforts. Native recolonization can augment active interventions if limitations to dispersal distance are recognized. These results should provide landowners and managers with the confidence to use techniques of varying intensity to restore ecosystem functions.

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1. Introduction

Reconstruction (*sensu* Stanturf, 2005) of forest conditions on former agricultural land is occurring in all forested regions of the world through passive (native recolonization) or active (afforestation) restoration. In the decade 1990–2000, global afforestation proceeded at the rate of 1.6 million ha annually (FAO, 2001). Recolonization by woody species into idle pasture and cropland was widespread especially in the Tropics and Eastern Europe (FAO, 2001). Afforestation in Europe and the United States is driven primarily by agricultural policy (Stanturf et al., 2000; Weber, 2005). There is ample evidence that if left alone abandoned agricultural land will develop into secondary forest although it may take considerable time (up to decades to develop a closed canopy) and could result in species composition that fails to meet management objectives. The literature on old field succession (cf. Cramer and Hobbs, 2007) is large and venerable and theories of old field succession informed much of the development of ideas about ecosystem dynamics, especially in North America (Cramer, 2007). Nevertheless, the considerable diversity in dispersal patterns (Nuttle and Haefner, 2005), the relative importance of abiotic and biotic barriers to seedling establishment (Grubb, 1977; Young et al., 2005), and the long-term effects of founder and filter species (Grime, 1998; Battaglia et al., 2007) all affect the composition of the forest that results. Most work on old field succession has been in upland systems; bottomland systems differ significantly in the effective dispersal of propagules by floodwaters, in addition to dispersal by wind and animals (Bonck and Penfound, 1945; Hopkins and Wilson, 1974; Battaglia et al., 2002) and by the interactive effect of microtopography and inundation regime on seedling establishment (Gardiner and Oliver, 2005).

In the last decade of the 20th Century, over 193,000 ha of cropland were afforested in the LMAV (Schoenholtz et al., 2001;

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Gardiner and Oliver, 2005), mostly on land cleared in the 1960s and 1970s primarily for soybean (*Glycine max* (L.) Merr.) production (Sternitzke, 1976). Cleared during a drought period, this land remained at risk for late spring and early summer flooding, and is returning to trees (Amacher et al., 1998; Stanturf et al., 2000; Schoenholtz et al., 2001). The decision by many landowners to afforest these lands has been aided in part by the increased availability of public incentive programs such as the Conservation Reserve (CRP) and Wetlands Reserve (WRP) Programs (Stanturf et al., 2000). Private programs have developed recently in anticipation of trading in carbon offset credits, led by the electric power industry (e.g., PowerTree Carbon Company, 2004). To date, the WRP has funded afforestation of the most hectares (Schoenholtz et al., 2005) using technology developed in the 1960s to establish commercial timber plantations (Allen, 1990; Newling, 1990; Allen et al., 2001).

Early results from the WRP were discouraging (Stanturf et al., 2001a); seedling survival rates were low, despite much available information on planting and direct seeding techniques (Stanturf et al., 1998; Allen et al., 2001; Gardiner and Oliver, 2005). Previous research work showed great promise but was done on small experimental plots and scaling up operationally to the landscape level was challenging. In response to questions from managers, we undertook a study to compare operational techniques for afforesting bottomland hardwoods. Although the basic techniques for afforesting native hardwood species have been worked out (Allen et al., 2001), few studies have directly compared several techniques on the same site in order to determine efficacy (Lockhart et al., 2003). We designed our study to examine four levels of restoration intensity in order to address both applied and more theoretical questions. Besides the standard approaches of direct seeding acorns and planting bare-root seedlings, we included a more intensive operation interplanting a fast-growing, native species eastern cottonwood (*Populus deltoides* Bartram ex Marsh. ssp. *deltoides*) with Nuttall oak (*Quercus nuttallii* Palmer), and the least intensive treatment of doing nothing and depending upon native recolonization. This restoration intensity gradient allowed us to look at the trade-off between effort and benefit from restored ecosystem functions (Hamel, 2003; Ciccarese et al., 2005). The objectives of the study were to compare four restoration techniques in terms of survival, accretion of vertical structure, and woody species diversity. Hypotheses tested included the test of no differences in woody plant stocking density and growth among alternative afforestation techniques and no difference in Nuttall oak growth in the open versus beneath the cottonwood overstory. Because we planted four cottonwood clones with different phenology, we included the hypothesis of no difference in Nuttall oak growth beneath the four cottonwood clones.

2. Methods

2.1. Study site

The study was located in Sharkey County, MS (lat 32°58′N long 90°44′W). The study site was in the Big Sunflower River drainage, part of the Yazoo River Basin. Historically the area was part of the floodplain of the Mississippi River. The study site was 2.5 km east of the town of Anguilla, immediately north of the Delta National Forest. The site was privately owned until acquired by the Federal government Farmers Home Administration through foreclosure. The tract was transferred to the U.S. Department of Interior Fish and Wildlife Service (FWS) in 1993 and is administered by the Yazoo National Wildlife Refuge (since rededicated as part of the Theodore Roosevelt National Wildlife Refuge Complex). The land was actively cropped until the study was established; cultivation for soybean production ended in the fall of 1994. Annual rainfall in Sharkey County averages 1318 mm, and mean temperatures range from 7.5 °C in January to 27.8 °C in July (Scott and Carter, 1962).

The hydrologic and edaphic conditions of the study site were typical of land available for restoration in the LMAV. Soils were mapped as the Sharkey series of very-fine, smectitic, thermic chromic Epiaquerts (Pettry and Switzer, 1996), by staff of the Natural Resources Conservation Service in 1994. Sharkey soils consist of poorly drained clays formed in fine textured sediment in slack water areas in the Mississippi River floodplain. The Sharkey series is one of the most extensively mapped soils in the United States, accounting for more than 1.5 million ha (Pettry and Switzer, 1996). The shrink-swell nature of these Vertisols result in 2–10-cm wide cracks up to 1.5-m deep that form under dry conditions, and close when saturated, Surface soils (0–7.5 cm) contained 42–71% clay; subsoil clay content typically ranges from 60 to 90% in the Sharkey series (Pettry and Switzer, 1996).

2.2. Experimental design

The experiment was a randomized complete block design with three replicates located to avoid minor depressions in different portions of the tract. The blocks were based on observed slight differences in elevation. During the study we observed backwater flooding in some years of portions of the site during the winter and early spring prior to leaf out. This occurs when drainage from the site is impeded by high water levels in the receiving water (streams and the Big Sunflower River) and may involve some overbank flooding from nearby drainage ways. In general, Block I was the driest and Block III the wettest. Treatment plots were 8.1 ha and approximately rectangular. Treatments were chosen to represent a gradient in restoration treatment intensity, from native recolonization, direct seeding Nuttall oak, planting Nuttall oak, to interplanting Nuttall with eastern cottonwood. The interplanting technique combined a fast growing species, eastern cottonwood, as a nurse crop for the slower growing Nuttall oak. Within the cottonwood plots, four clones were planted in clonal subplots, 2-ha in size. Cottonwood is very intolerant of shading and intensive competition control is required to insure survival (Stanturf et al., 2001b). Thus, oak interplanting was delayed until after the cottonwood's second growing season. This planting pattern left an interrow without oak seedlings, which will allow directional felling and removal of the cottonwood with minimal damage to the oak seedlings, as the cottonwood can be harvested in as little as 10 years, providing an opportunity to manipulate canopy structure and a financial return to the landowner.

In a separate experiment, we examined the effect on cottonwood growth and survival of disking 1 year versus 2 years after planting by splitting each clonal subplot; one sub-sub-plot was disked twice during summer 1995 and the other sub-sub-plot was disked twice in each of the 1995 and 1996 growing seasons.

2.3. Establishment

All treatment plots were site prepared by disking. Two blocks (II and III) were disked in November 1994 but Block I became too wet for machines. Blocks III and I were disked in February 1995, just before planting. Locally grown bareroot 1–0 Nuttall oak seedlings (Fratesi Nursery, Leland, MS) were machine planted by FWS staff in March 1995 at 3.7 by 3.7-m spacing (730 seedlings/ha). Viable acorns that had been collected from nearby natural stands were machine sown by Fish and Wildlife Service staff in May 1995. Spacing was 1.1 by 3.7 m (2457 acorns/ha), with one acorn placed at each planting spot. No additional site preparation or tending was applied to the direct seeding, seedling planting, or native recolonization treatments, following standard practice under the WRP.