Achieving Restoration Success: Myths in Bottomland Hardwood Forests

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Abstract

Restoration of bottomland hardwood forests is the subject of considerable interest in the southern United States, but restoration success is elusive. Techniques for establishing bottomland tree species are well developed, yet problems have occurred in operational programs. Current plans for restoration on public and private land suggest that as many as 200,000 hectares could be restored in the Lower Mississippi Alluvial Valley alone. The ideal of ecological restoration is to reestablish a completely functioning ecosystem. Although some argue that afforestation is incomplete restoration, it is a necessary and costly first step but not an easy task. The 1992 Wetlands Reserve Program in Mississippi, which failed on 90% of the area, illustrates the difficulty of broadly applying our knowledge of afforestation. In our view, the focus for ecological restoration should be to restore functions, rather than specifying some ambiguous natural state based on reference stands or pre-settlement forest conditions. We view restoration as one element in a continuum model of sustainable forest management, allowing us to prescribe restoration goals that incorporate landowner objectives. Enforcing the discipline of explicit objectives, with restoration expectations described in terms of predicted values of functions, causal mechanisms and temporal response trajectories, will hasten the development of meaningful criteria for restoration success. We present our observations about current efforts to restore bottomland hardwoods as nine myths, or statements of dubious origin, and at best partial truth.

Key words: **afforestation, functions, Wetlands Reserve Program.**

Introduction

Restoring degraded ecosystems is a major new focus of research and practice (National Research Council 1992; Cairns 1995). Nevertheless, the scientific basis for ecological restoration is thin. Many authors stress the need for clear objectives in a restoration project, in order that indicators of restoration success can be specified. Anderson and Dugger (1998) provide a conceptual basis for evaluating success, and Toth and Anderson (1998) describe a very complete set of indicators for one of the largest and most expensive restoration projects in the United States, the Kissimmee River in Florida. Restoration of bottomland hardwood forests is the subject of considerable interest in the southern United States (Clewell & Lea 1990; Sharitz 1992; Noss et al. 1995), although there is little consensus on what constitutes restoration success. Techniques for establishing bottomland trees species are well developed (Allen & Kennedy 1989; Stanturf et al. 1998*b;* Allen et al. in press), yet problems have occurred in operational programs. In this paper, we share experience and insight gained from our research projects, technology-transfer activities and training programs. We believe that many problems stem from misunderstanding the ecology of bottomland hardwood forests, unclear restoration objectives or resistance to new methods and approaches. We synthesized our observations into nine statements about restoration of bottomland hardwoods that we characterize as myths, or statements of dubious origin, and at best partial truth. To assist in understanding the origin and significance of these mythical statements, it is necessary to place them in their ecological and sociopolitical context.

Ecological Context

Restoration of forested wetlands requires an understanding of site variation within floodplains and the site requirement of the species to be used. Although most

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floodplains are relatively flat, large differences in site quality and species suitability occur due to small changes in topography. Many unsuccessful restoration projects foundered by failing to recognize these differences. Changing elevation by a few inches can have a marked effect on site quality, and thereby on species occurrence and stand development (Hodges & Switzer 1979; Wharton et al. 1982; Hodges 1997, 1998). Differences in hydroperiod, soil drainage and aeration and soil redox potential are associated with these minor elevation changes. They also reflect differences in soil texture, structure and pH, which all affect species suitability for a particular site (Baker & Broadfoot 1979).

The origin and development of floodplain geomorphic features are discussed in basic texts on fluvial geomorphology and wetlands (Mitsch & Gosselink 1993). The significance of these features in patterning floodplain vegetation has been described in detail by Hodges (1997, 1998) and Kellison et al. (1998); the specific soil relationships are summarized in Stanturf and Schoenholtz (1998). In summary, fronts and ridges are the highest, best-drained and most productive sites within the floodplain. Soils are generally sandy or silty loams. Soils on flats are predominantly clays and these sites are poorly to somewhat poorly drained. Sloughs and swamps arise from old streambeds which are almost filled or are being filled with sediment. The soils in sloughs and swamps are generally fine textured, at least in surface horizons, and drainage is poor. Standing water may be present in swamps except in extremely dry years.

A knowledge of stand development and replacement patterns on bottomland hardwood sites is important for long-term success of restoration projects. In addition to the kinds of overstory disturbances and plant-mediated responses as occur in uplands, bottomland sites change over time by deposition of sediment and meandering of the river. Hodges (1997) recognized three general patterns of stand replacement in major river bottoms. On permanently flooded sites where little deposition occurs, such as Taxodium-Nyssa swamps, compositional changes may not occur for hundreds of years absent major disturbances such as hurricanes (Conner & Buford 1998). The Taxodium-Nyssa type often is the oldest community in a floodplain, with the oldest individuals. Stands can be as young as 200-300 years old before replacement occurs.

Another pattern can be discerned on poorly drained sites at low elevation that are not permanently flooded. The pioneer tree species on these sites with heavy soils is usually *Salix nigra* Marsh (black willow). Break-up of willow stands may begin as early as age 30 and few remnants survive beyond age 60 (Johnson & Shropshire 1983). Development of the vegetation depends on the rate of sediment deposition and sometimes on the texture of the sediment. Although there are several pathways, development tends toward the *Ulmus–Fraxinus–Celtis* (elm-ash-hackberry) type, which is the most common community in the major bottoms of the Mississippi River alluvial plain and the western Gulf of Mexico coastal plain.

The third pattern, termed the riverfront association, occurs on the higher elevation, better-drained ridge and front sites. *Populus deltoides* var. *deltoides* (Bartr.) ex Marsh (Eastern cottonwood) is the pioneer species on “new land” formed by exposure of point bars, or after major stand-removing disturbances that expose bare mineral soil. This community does not last long; cottonwood stands begin to break up at age 45 or earlier, but remnant stems may survive on these highly productive sites until age 80-100 years (Johnson & Shropshire 1983). Stand composition following cottonwood can vary, depending on how quickly replacement occurs. Shade-tolerant species such as *Acer negundo* L. (boxelder), *Celtis laevigata* Willd. (sugarberry), *Acer saccharinum* L. (silver maple) and *Celtis occidentalis* L. (hackberry), usually well established beneath cottonwood, will capture the site if the break-up is gradual. If stand replacement is rapid, species composition of the subsequent stand depends on presence of advance regeneration and the ability of shade-intolerant species to establish. In the Mississippi River system between the protecting levees (batture), composition is commonly *Platanus occidentalis* L. (American sycamore), *Carya illinoensis* (Wangenh.), K. Koch (pecan) and *Ulmus* spp. (elms). Other species present can include *Fruxinus* spp. (ashes), *Liquidambar styraciflua* L. (sweetgum), *Quercus phellos* L. (willow oak) and Q. *nigra* L. (water oak). The riverfront association may persist for 75-125 years. The long-term tendency is toward the *Ulmus–Fraxinus–Celtis* association, which may replace itself and persist for 200-300 years. A transitory *Liquidumbur-Quercus* type can occur following natural disasters or heavy cutting, but this depends upon the presence of advance oak regeneration, coppice regeneration or both. The *Liquidumbur-Quercus* type may persist for 200 years or longer. When flooding frequency diminishes, sedimentation ceases and soils begin to mature, the site begins to function more like a terrace than a ridge. Other oaks such as *Q. falcata var. pagodaefolia* Ell. (cherrybark oak), *Q. palustris* Muenchh. (pin oak) and Q. *michauxii* Nutt. (swamp chestnut oak), adapted to better drained conditions, will appear.

Sociopolitical Context

The original extent of southern bottomland hardwood forests was probably around 40-50 million hectares before European settlement (The Nature Conservancy 1992). These forests occur mostly in the floodplains of major rivers and their tributaries within the broad

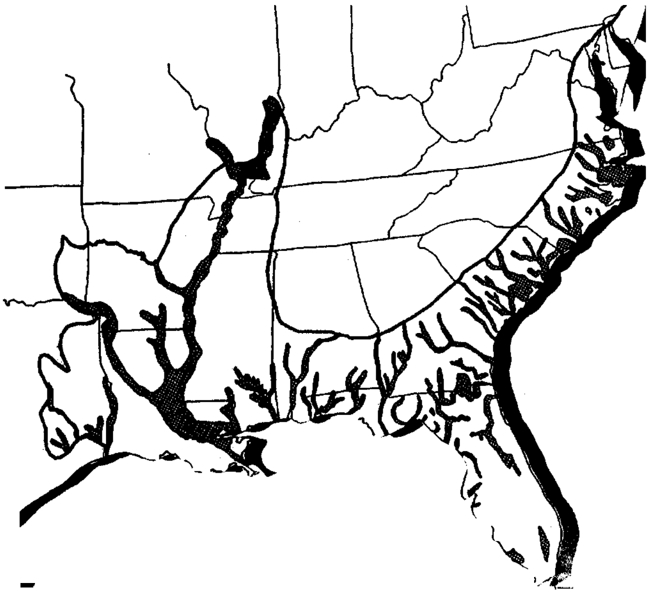

Figure 1. Present extent of bottomland hardwood ecosystems in the southern United States. Inset map indicates the location of the Coastal Plain and Lower Mississippi River Valley physiographic provinces which contain most of the bottomland hardwood forests.

coastal plain stretching from Virginia to Texas (Fig. 1). Most of our research is concentrated in the Lower Mississippi Alluvial Valley, where about 2 million hectares of bottomland hardwood forests remain of an original 8-10 million hectares (MacDonald et al. 1979). The highly fertile soils in this region were cleared for agriculture and major crops today are cotton, rice, soybeans, wheat, aquaculture and sugarcane (McWilliams & Rosson 1990).

Extensive clearing of this land for agriculture began in the early 1800s and continued sporadically through the 1970s. The forest in 1800 was likely secondary succession, resulting from abandonment of extensive Native American agricultural fields upon loss of human population to diseases in the late sixteenth century (Hamel & Buckner 1998). The latest episode of clearing was driven by a steep rise in soybean prices, the development of short season varieties that could be grown profitably on lower lying land and an extended dry period (Sternitzke 1976). But many hectares were cleared that remained subject to late spring and early summer flooding, and remain uneconomical for cropping. This land is now being restored to forests under the Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP), both administered by the U.S. Department of Agriculture (Kennedy 1990; Shepard 1995; Stanturf et al. 1998b).

In addition to programs on private land, afforestation of public land is underway by federal and state agencies. The U.S. Fish and Wildlife Service began an aggressive afforestation program in the Lower Mississippi Alluvial Valley, beginning in 1987 (Haynes et al. 1995), on both refuge land and in partnership with adjacent private landowners. The U.S. Army Corps of Engineers must mitigate forested wetland losses caused by construction projects, generally to control flooding. One ambitious project is the Lake George property in the Yazoo River Basin in Mississippi (U.S. Army Corps of Engineers 1989). State government agencies in the Delta states of Mississippi, Arkansas and Louisiana have undertaken their own afforestation projects (Savage et al. 1989; Newling 1990). Current plans for restoration on public and private land suggest that as many as 200,000 ha could be restored in the Lower Mississippi Alluvial Valley alone (Table 1).

Myth 1. Afforestation Is Not the Same as Restoration

Although some argue that afforestation is incomplete restoration, it is a necessary and costly first step. The ideal of restoration is to reestablish a completely functioning ecosystem. But we know little about establishing understory species (Walker & Boyer 1993; Packham et al. 1995) and even less about non-vegetative components such as soil quality (Parrotta 1992; Doran & Parkin 1994). Fortunately, most functional attributes are correlated to vegetation composition and structure (Cairns 1986).

Table 1. Potential afforestation in the Lower Mississippi Alluvial Valley[a]

Program	*Agency* [b]	*Area (ha) in 1995*	*Area (ha) Planned to 2005*	*Total Area (ha)*
Wetlands reserve	NRCS	53,000	47,750	100,750
Wildlife refuges	USFWS	5,180	10,000	15,180
Wetland mitigation	COE	2,025	9,700	11,725
State agencies	MS, AR, LA	13,500	40,500	54,000
Total		73,705	107,950	181,655

[a] Estimates were provided by participants at a workshop, Artificial Regeneration of Bottomland Hardwoods: Reforestation/Restoration Research Needs, held in Stoneville, Mississippi, on 11-12 May 1995.

[b] NRCS, Natural Resources Conservation Service; USFWS, U.S. Fish and Wildlife Service; COE, U.S. Army Corps of Engineers; MS, Mississippi; AR, Arkansas; LA, Louisiana.

While there is more to restoration of a bottomland hardwood ecosystem than afforestation, it is hard to envision a successful restoration program that does not restore forested conditions. Even more problematic is who would bear the cost of attempting complete restoration of such large areas (Table 1). Even if the emphasis is on restoring hydroperiod, evapotranspiration of the forest canopy is a driving component of wetland hydrology (Williams 1998) and hydroperiod in bottomland hardwood systems cannot truly be restored absent forest condition. It is irrational to contemplate reestablishing the pre-settlement hydroperiod of the Mississippi River. However, it is feasible to restore local drainage on restoration sites to foster wetter conditions, particularly during the dormant season. Ponding water through the winter and removing it before the growing season mimics seasonal fluctuations. Flooding agricultural fields during the winter is increasingly common, undertaken to enhance waterfowl habitat. Because the Lower Mississippi Alluvial Valley is so flat, this approach will require ongoing water management to protect neighboring landowners and to prevent the takeover of the site by beaver (Castor *canadensis*).

Myth 2. Restoration Is Easy-Anyone Can Do It

A related myth is that restoration, viewed as afforestation of small tracts within a landscape matrix of intensive, row-crop agriculture, is easy and anyone can specify how to restore a site. While we know how to afforest many sites (Kennedy 1993; Stanturf et al. 1998*b*), recent experience with the WRP in Mississippi illustrates the difficulty of applying this knowledge broadly. Afforestation is a system where something can go wrong with any or several steps. We have observed problems with poor seed sources, improper storage or handling of seed and seedlings, prescribing species that were not adapted to the site, and poor planting techniques. In addition, there are the natural factors out of our control such as unusually late flooding, droughty spring after planting and deer and small mammal depredations.

We surveyed the success of the WRP in Mississippi in 1992 (C. J. Schweitzer, unpublished data). The WRP pays the costs of planting trees on farmland that floods frequently, and further pays for a conservation easement. The one-time, lump-sum easement payment is to compensate the landowner for loss of income from farming. The farmer can elect to provide an easement for 30 years or in perpetuity, and the payment is adjusted accordingly (Shepard 1995). There were 4,000 ha placed in the program in fiscal year 1992, representing 47 parcels of land, each approximately 85 ha in size. The standard of success used by the contracting agency, the Natural Resources Conservation Service, is at least 247 stems per hectare of acceptable species (mostly native, dominant canopy species) after 3 years. This standard allowed for volunteer species as well as those planted or direct seeded by contractors. Only two tracts were successfully afforested by this standard (C. J. Schweitzer, unpublished data). On an area basis, this is a 90% failure. We believe higher stocking should be attempted—750 stems per hectare. This can be achieved by planting more seedlings, by applying more intensive weed control or by both. By our more restrictive standard, only one parcel was successfully afforested and it adjoined a natural stand and received windblown seed. We estimated the cost of this program, in one state in one year, at $4.5 million. Replanting the failures will cost a further $500,000 (F. Woods, personal communication 1997).

What went wrong? Although we cannot be certain, indirect evidence points to two main causes for failure: species were not adequately matched to sites, and oversight of the contractors was insufficient. It would be easy to regard this experience as unusual, but in fact few restoration projects are subjected even to a cursory post-operation evaluation (Anderson & Dugger 1998).

Myth 3. Desired Future Condition Can Be Specified

After disposing of the myth that afforestation bears no resemblance to restoration and the myth that restoration is easy, we are left with the question of what constitutes restoration. What are our objectives, and how can they be specified in a measurable indicator of success? Most practitioners seem to favor the use of reference sites (Brinson & Rheinhardt 1996; Anderson & Dugger 1998). Restoration guidelines usually recommend identifying older, relatively undisturbed reference stands as the criteria for successful restoration. Alternatively, the goal is less specific, to restore the site to natural conditions as embodied by some notion of the pre-settlement forest. We regard both versions of the desired future conditions of the restoration site as problematic.

Problems with Reference Stands

Reference stands for bottomland hardwoods in the Lower Mississippi Alluvial Valley probably have hydroperiods altered by the same levee system and regional drainage that permitted the degraded site to be cleared and farmed. Extensive levee and drainage construction have isolated large areas of the Lower Mississippi Alluvial Valley from infrequent but regular flooding of the mainstem Mississippi River and its tributaries. Sites in the Lower Mississippi Alluvial Valley on the protected side of the levees are "drier" now than historically, and older stands in some areas were therefore established under wetter conditions. One consequence is that the current preference for establishing oak plantations (Haynes et al. 1995) on wildlife management areas could result in greater occurrence of oak regionally than was typical of pre-settlement forests (The Nature Conservancy 1992). Conversely, an incomplete regional drainage project on the Yazoo River in Mississippi has resulted in wetter conditions in the southern half of the Yazoo basin than historically, making it difficult to establish the species of bottomland hardwoods that occurred in the pre-settlement forests.

The interaction of plant succession and hydroperiod under natural conditions is dynamic and complex. When one or both have been altered by human intervention, however, the present condition of the reference site may not be the same as when the stand was initiated. Thus, the site factors that shaped the development of the restoration stand are no longer present, and the present stand is not a good indicator of the stand that would develop under the present site conditions. Clewell and Lea (1990) pointed out the drawbacks of using specific reference forests to gauge success, including the lack of similarity in stands of the same community type due to accidents of dispersal or localized disturbances. To this we would add that past stand manipulation, either by silvicultural treatments or by high-grading, would have changed species composition and stand structure.

Although there are drawbacks to using reference sites to measure success, they may be useful in defining goals. A restoration site, once developed, should fit within the range of species composition and stand structure for that forest type, as it occurs in the vicinity (Clewell & Lea 1990). Hydroperiod restoration should aim at establishing a diversity of sites within the range of wetland types in the landscape (Bedford 1996). Reference sites can be chosen which represent target conditions for the restoration site. Care must be taken, however, to establish a hydrological record for both the restoration and reference sites. When comparing the restoration and reference stands, one should always take into account temporal variability of stand conditions. We have to recognize that there are often multiple pathways of stand development (Oliver & Larson 1996; Parker & Pickett 1997) and functional attributes such as biodiversity will change as a stand develops.

Disturbance regimes and past land use can dramatically influence present vegetation of reference stands. For example, we are intensively studying a minor river bottom, Iatt Creek, in central Louisiana. This relatively undisturbed bottomland ecosystem on the Kisatchie National Forest is representative of approximately 7 million hectares of minor bottoms across the South. A vegetation ordination and a soil survey (Gardiner et al. 1996) have shown that higher, terrace-like sites within the 300-ha study area are occupied by more mesic species such as *Fagus grandifolia* Ehrhart (American beech). Soil profiles contain a distinct buried A (surface) horizon at approximately 1.5 m, evidence of considerable sediment deposition since European settlement (C. Meier, unpublished data). Accelerated erosion of the uplands within the basin by cotton farming in the nineteenth century was the most probable cause (W. Hudnall, personal communication 1998).

Problems with Pre-Settlement Forest

We are just beginning to realize that our notions of pre-settlement forests are oversimplified. Hamel and Buckner (1998) suggested three points in time that could be used as the reference pre-settlement forest to represent the natural state. We can use the immediate post-glacial forest (approximately 15,000 years before present) that included many boreal and northern species that are ill-adapted to today's climate. This is the only reference for conditions when anthropogenic effects were minimal. Alternatively, the forest as it was immediately prior to European settlement (1492) is usually chosen. However, population levels of indigenous peoples were higher than most people today realize, and extensive areas were cleared periodically by slash and burn (shifting cultivation) or even semi-permanent agriculture. What is usually taken as the condition of the pre-settlement forest is that found by the early settlers and literate travelers (Bartram 1791) in the seventeenth and eighteenth centuries. These latter forests actually developed in old fields or in fire-maintained communities, after abandonment by the indigenous peoples who were decimated by introduced diseases such as measles, typhus, malaria and small pox. It is critical to realize that these diseases spread from earliest contact with explorers, trappers and traders long before European settlements were established. Although the magnitude of Native American populations is fiercely debated, the consensus among anthropologists is that populations declined 90% in the 1500s (Whitmore 1991; Lovell 1992). Thus the forest primeval found in 1607 (the date of the first permanent English settlement) was the result more of changing human intervention and land use than from ecological processes in a stable natural forest. As Oliver and Larson (1996) have argued, it is doubtful that steady-state conditions ever existed in North American forests. If nothing else, climatic variation in the Holocene has profoundly shifted distribution of individual species. Historical plant communities existed for which we have no modern day analogs (Devall & Parresol 1998). Future shifts in climatic extremes, such as increased frequency of hurricanes, fires and drought, could severely impact development of restoration stands in the future. Rising sea level will disproportionately affect coastal wetlands in addition to plant communities in the entire Lower Coastal Plain (Devall & Parresol 1998) due to raising the base level and changing flooding extent, frequency and duration.

Focus on Restoring Functions, Not on Naturalness

What should be the target for ecological restoration? Hamel and Buckner (1998) concluded that this is a sociopolitical question. To make informed choices, we suggest focusing on restoring functions, rather than specifying some ambiguous natural state. We can set objectives for achieving levels of functions and develop techniques for establishing the forest communities that produce the desired conditions. If we build into our expectations that a time element is involved in restoration, we can describe our expectations in terms of a predicted value, a mechanism and the temporal response trajectory (Toth & Anderson 1998). The predicted value for a function specifies where the values for a function are going. Understanding the mechanism by which we reach the predicted value enables us to comprehend the intermediate values the function will have over time, the temporal response trajectory. Different functions will have their own timeframes.

Data from one of our studies (S. H. Schoenholtz, unpublished data) will illustrate this approach. We quantified the effect of restoration on soil quality by sampling a chronosequence of stands on the same soil series and landform position. We chose as representative of many Wetlands Reserve Program sites the Sharkey clay (very fine, montmorillonitic, non-acid, thermic vertic Haplaquepts; Pettry & Switzer 1996), nearly level phase (0.5–2% slope, not subject to backwater flooding). We sampled *Quercus nuttallii* Palmer (Nuttall oak) stands in four age classes: newly planted sites, plantations aged 5-8 years, plantations aged 18-25 years and natural stands about 60 years old. We sampled three stands in each age class for soil properties at several depths. Figure 2 illustrates the average values for soil organic carbon in the O-5 cm depth and bulk density of the surface 10 cm, across the chronosequence. There appears to be a pronounced, immediate impact of increasing soil carbon and decreasing bulk density within the first 5-10 years, and then a more gradual trajectory. The mechanisms accounting for the carbon response are increasing return of plant material to the upper soil horizons from leaf litter return to the surface and fine root turnover in the upper soil horizons, in concert with lower decomposition rates from lower soil temperatures and less soil disturbance (i.e., cessation of soil tillage). The decrease in bulk density results from cessation of machine traffic, proliferation of woody roots (which increases porosity) and protection of the soil surface from raindrop impacts by the developing tree canopy.

Twedt et al. (1999) provide another example of the recovery of a different function. They compared avian densities in natural bottomland hardwood forests to short-rotation Eastern cottonwood plantations as well as farmland afforested with cottonwood. Partial cutting of natural stands shifted avian communities toward intensively managed cottonwood plantations, although within 6 years the avian communities were the same in cut and uncut natural stands. Avian community structures within managed cottonwood plantations changed markedly as stands aged to about 5 years; if planted cottonwood stands were allowed to develop into bottomland hardwood stands, avian communities appeared to be similar to those in natural stands. If cavity nesters were excluded from the analyses, natural bottomland hardwood stands and managed cottonwood stands were alike in terms of avian species richness and territory density. When compared to other studies of agricultural fields or grasslands, managed cottonwood plantations were more like forests in terms of avian territory density.

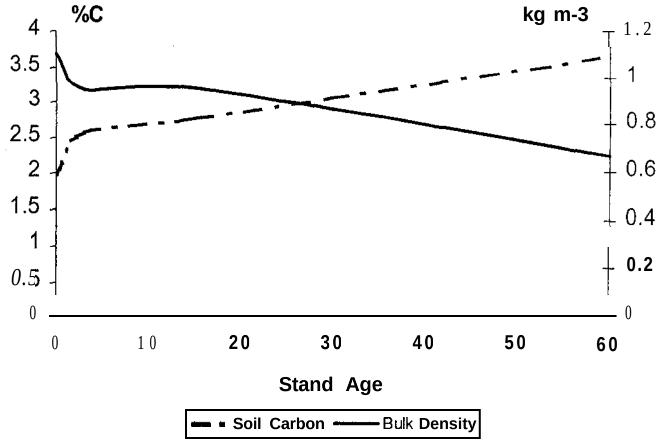

Figure 2. Temporal response trajectories for soil organic carbon and bulk density in bottomland hardwood afforestation. Values developed from a chronosequence of *Quercus nuttallii* plantations and natural bottomland stands on Sharkey clay soils in northwestern Mississippi. The values for soil carbon (left y-axis) and bulk density (right y-axis) are for the upper 5 cm of soil.

Myth 4. The Same Strategy Is Appropriate to All Ownerships

The strategies used to afforest bottomland hardwoods cover a spectrum from extensive (plant seedlings or direct-seed acorns) to intensive techniques for creating multi-species stands. The dominant goal of all restoration programs in the Lower Mississippi Alluvial Valley, whether on public or private land, has been to create wildlife habitat and improve or protect surface water quality. The extensive strategy that predominates on public land has shaped the federal programs aimed at private land. While the extensive strategy may be appropriate on public land, an arguable proposition, it is not always appropriate for private land (Stanturf et al. 19984.

The extensive strategy seeks the lowest establishment cost per hectare and usually involves widely-spaced plantings of heavy-seeded species of value to wildlife such as *Quercus* spp. These are planted as 1-O bareroot seedlings or direct-seeded acorns because they are the most difficult to obtain by natural processes. The manager then relies on wind and water to disperse light-seeded species such as ash, elm and maple (Stanturf et al. 199%). The light-seeded species are needed for diversity and to fill in the space between the oak seedlings, in order to fully occupy the site and to create forested conditions (Allen 1990; Haynes et al. 1995). This strategy on private land is flawed on several counts. First, wind and water dispersal of light-seeded species to these small, isolated tracts is unreliable if natural seed sources are more than 100 m away (Allen 1990; Allen et al. in press). Second, more intensive strategies are available that provide wildlife benefits and restore forested wetland functions more quickly. Third, the stocking that results from successful federal cost-share programs (i.e., 257 stems per hectare at age 3) will not be sufficient to support a commercial pulpwood thinning even at age 20 or 30 years (Goelz 1997), rendering timber production infeasible and limiting opportunities to shape stand structure.

We have demonstrated more intensive strategies of establishing a closed-canopy forest quickly, albeit at higher initial cost than the extensive techniques (Schweitzer et al. 1997). In the interplanting technique, a manager establishes a closed-canopy forest in 2 years, using fast-growing native species such as Eastern cottonwood. Once this nurse crop is established, slower growing species of oak (we used Nuttall oak in our study) can be interplanted between every other row of cottonwood. Later, the manager will intervene to shape stand structure and composition of the stand as it develops. Possibilities include harvesting the cottonwood at age 10, in the winter to maximize sprout growth and afford the manager a second coppice rotation of the cottonwood, or in the summer to minimize cottonwood sprouting and release the oak seedlings. Alternatively, the landowner could selectively harvest the cottonwood (for example, by mechanically thinning every other row of cottonwood), thereby partially releasing the oak saplings. If the thinning takes place in the winter and sprouting occurs, a second age class of cottonwood is possible. Another option would be to remove all but a few cottonwood in the summer, completely releasing the oak saplings and retaining some *Populus* to develop cavity trees. If these stands have developed similarly to managed cottonwood plantations in the Lower Mississippi Alluvial Valley, there should be significant advance reproduction of light-seeded species such as ash and elm in the understory that will be released with the oak saplings (Twedt & Portwood 1997).

Myth 5. Plantations Have No Wildlife Value

Underlying the extensive strategy is a disdain for plantations of any species, but especially cottonwood because plantations are monocultures bereft of wildlife value. Several studies have shown the value of even intensively managed cottonwood stands to wildlife (Twedt & Portwood 1997; Twedt et al. 1999; Wesley et al. 1981). Some wildlife managers believe the low-cost, widely spaced stands produced by the extensive approach will meet their objectives. But even when natural invasion successfully increases stocking, it will be 20 years or more before forested stand conditions develop (Allen 1990). During that interval, significant opportunities will be missed to provide habitat for Neotropical migratory birds (Twedt & Portwood 1997; Twedt et al. 1999) and other wildlife (Wesley et al. 1981). Additionally, managers will have few opportunities to manipulate these understocked stands to further enhance wildlife habitat in the future. A more intensive approach (increased stocking of single or multiple tree species) would provide greater diversity at both the stand and landscape levels more quickly, and provide opportunities for shaping stand structure and composition.

Myth 6. Understocked Stands Are Sufficient

Resistance to intensive methods arises from disagreement over stocking levels. Adequacy of stocking, and the planting density necessary to achieve it, depend on objectives. If the objective is to restore forested conditions and if we use time to canopy closure as a measure of success, the tradeoffs are estimated in Fig. 3. Across the ordinate axis we have arrayed four techniques used in the Lower Mississippi Alluvial Valley for afforestation, in order of increasing intensity. The least intensive method is to do nothing after ceasing cropping, and allow natural succession to take its course. The two most common afforestation methods are direct-seeding acorns or planting oak seedlings by wide spacing, 3.6 X 3.6 m. The most intense practice is interplanting cottonwood on 3.6 X 3.6 m spacing, with oak interplanted on 7.2 X 3.6 m spacing. Time to canopy closure is shown on the left-abscissa and cost per hectare on the right-abscissa (Fig. 3). We estimated time to canopy closure by calculating the distance between trees to be approximately 5.7 m, assuming uniform spacing at the target density (309 stems per ha). The dbh of an open-grown Nuttall oak with a crown radius of 2.9 m was estimated from Goelz (1996) to be 17.8 cm. Results of a spacing study (Carlson & Goelz 1998) were extrapolated to estimate the time to grow a tree to this diameter, approximately 40 years.

While the time to canopy closure values are open to debate, the overall picture is accurate: obtaining resto-

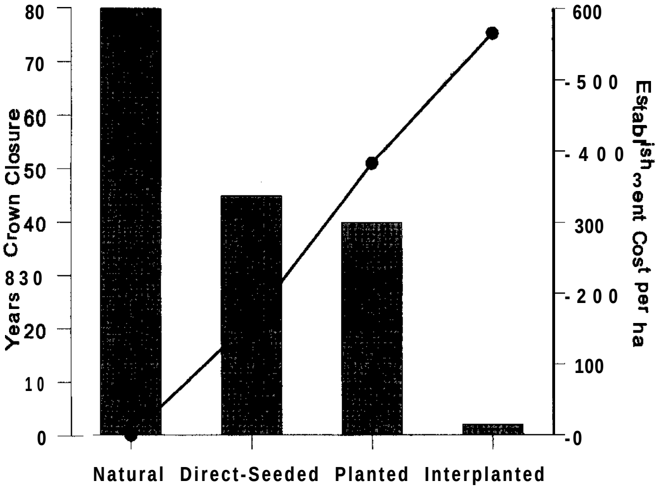

Figure 3. Time to canopy closure, one measure of restoration success, arrayed against four afforestation techniques in order of increasing effort and cost, from allowing natural succession (lowest intensity, lowest establishment cost) to interplanting fast-growing Eastern cottonwood with Nuttall oak (highest intensity, highest cost). The solid line indicates cost in $US per hectare for establishment (right y-axis).

ration benefits quickly, costs more money. If time to canopy closure and regaining vertical structure are useful measures of restoration success, then the intensive method achieves success in 2 years versus 2040 years for current methods. An intermediate approach would be to double the current planting density, with a target stocking of more than 500 stems per hectare of oak seedlings at age 3. An area of future research should be the most cost-effective ways to directly produce mixed species stands by interplanting.

Myth 7. Preservation Is the Only Valid Goal

A prevalent myth is that preservation of the restored stand is the only valid goal of restoration programs. Private landowners are viewed as interested in restoration only if they are compensated, and if they are paid to participate they have no right to expect to receive income from the restored forest. Restoration programs in the Lower Mississippi Alluvial Valley, therefore, have evolved into land retirement programs, which was not the intent of the legislation that established and funded programs such as the Wetlands Reserve Program (H. Shipman, personal communication 1997).

We view restoration differently and see it as an element in a continuum model of sustainable forest management (Walker & Boyer 1993; Stanturf & Meadows 1996). This can be illustrated by Figure 4, adapted from the figure used by Maini (1992) to illustrate the renewal

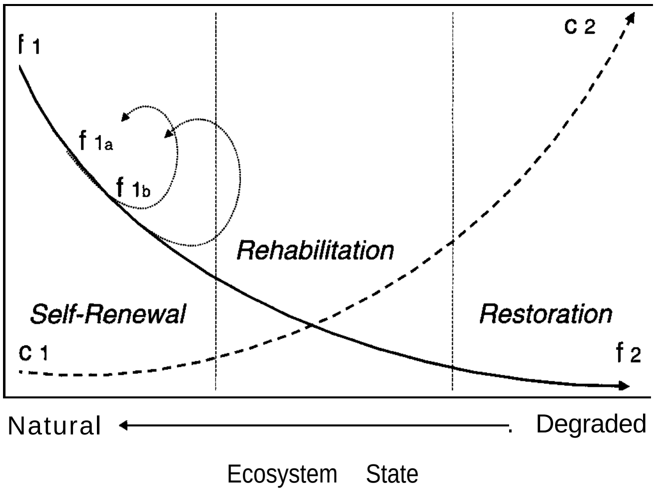

Figure 4. The continuum model of sustainable forest management (adapted from Maini [1992]). The state of the forest ecosystem ranges from natural to degraded (x-axis) and levels of state factors (left y-axis) change in response to disturbance along the solid line (f_1–f_2), the forest degradation trajectory. Cost of recovery (right y-axis) follows the dashed line (c_1–c_2). The recovery pattern is divided into three levels characterized by the extent of management intervention: self-renewal, rehabilitation or restoration. In the self-renewal phase, the forest can return to its original state, more or less, without human intervention in a relatively short time (indicated by the lines f_1–f_{1a} and f_1–f_{1b}).

capacity of forests and their responses to stress. The state of the forest ecosystem ranges from natural to degraded. Levels of state factors such as biomass or biodiversity in forests subjected to disturbance follow the solid line (f_1–f_2), the forest degradation trajectory. The actual shape of the trajectory is characteristic of the state factor. At any point along the line, recovery can be initiated once the stress or disturbance abates. The recovery pattern is divided into three levels: self-renewal, rehabilitation or restoration. In the self-renewal phase, the forest can return to its original state, more or less, without human intervention in a relatively short time (indicated by the lines f_1–f_{1a} and f_1–f_{1b}). Natural regeneration of forests managed for timber is an example of reliance on self-renewal processes. At intermediate levels of disturbance, it will take longer to recover naturally, but the time required may be shortened by human intervention. One example might be rehabilitation by reforestation of forests consumed by wildfire. At their most degraded state, forests may recover naturally after a century or more, but after only decades with human intervention.

The forest that results from restoration may never recover to the original state for all functions (see Harrington 1999 for a graphical representation of possible trajectories). Our usage of restoration differs from the otherwise very satisfactory terminology of Bradshaw (1997), as we do not accept the "ideal state" connotation he gives it. If we can move the ecosystem from the degraded to the natural state, we can then depend upon self-renewal processes in managing the resulting forest. How quickly the forest moves to the self-renewal phase is a function of the amount we are willing to invest to overcome the degraded conditions, the dashed line (c_1–c_2). This line may shift its vertical position depending upon available silvicultural techniques. The continuum model not only avoids the meaningless exercise of specifying an endpoint for restoration, but it offers a broader context for restoration on private land. Landowners with management objectives other than preservation are able to contribute to ecosystem restoration (Stanturf et al. 1998*a*).

Myth 8. Ecological and Economic Goals Are Incompatible

A related myth is that ecological and economic values are incompatible and that we must choose at the most basic level between timber production and preservation. Ecological and economic goals are not mutually exclusive. A win-win situation is possible, especially on land owned by small non-industrial private landowners who are generally not interested in maximizing commodity outputs. A landowner may focus on benefiting wildlife, disregarding financial return even as a secondary objective. Nevertheless, harvesting some timber may be in his or her best interest because the easiest way to benefit wildlife may be the vegetation structure that results from thinning a young stand. The proceeds from sale of the pulpwood removed can offset at least some of the costs of habitat improvement. This income eases the financial burden of improving habitat and ensures that the enhancement actually occurs. Financial returns can help pay for restoration costs, aftercare expenses and landholding expenses such as taxes and management, thereby achieving a higher level of restoration benefit. This same rationale can be applied to public lands where appropriations for management are shrinking.

Myth 9. Restoration Can Proceed Without Management

We have taken a decidedly pro-management stance throughout this paper, in contrast to a prevailing myth that restoration can proceed without ongoing management. Many restoration projects are conceived as requiring little or no intervention once the original investment is made, as it is wrongly assumed that a self-renewing forest has been established. Certainly the extensive strategy for restoring bottomland hardwoods in the Lower Mississippi Alluvial Valley is an example of a "plant and walk away" mentality. We have argued for consideration of more intensive strategies for two reasons: first, the extensive strategy does not meet program objectives of restoring forest conditions; and second, the greater benefits that accrue from more intensive techniques outweigh their higher costs. Other restoration goals can be met by restoring hydroperiod but this requires ongoing water management. Initial confusion over who had responsibility for maintaining existing drainage structures on land under permanent easement within the Wetlands Reserve Program has been resolved, with the landowner retaining responsibility (F. Woods, personal communication 1998).

Conclusions

Restoration is not easy; in practice, afforestation has been difficult when attempted on a large scale. Complete restoration, in the sense of completely restoring all functions of an intact bottomland hardwood ecosystem, may not be achievable. For the foreseeable future, restoration will be afforestation of potential overstory species. We must do a better job of this first step in restoration. The majority of bottomland hardwood restoration will be on private land enrolled in the Wetlands Reserve Program where intensive restoration currently is allowed only on a few demonstration sites, although it has occurred under the Conservation Reserve Program (J. Portwood, personal communication 1998). Much research in progress will sharpen our understanding of the economic as well as the ecological values of these forests. We continue to develop and test restoration techniques (Schweitzer et al. 1999). For most landowners, costs and the availability of incentive programs will continue to determine the kinds of restoration undertaken.

Viewing the restoration effort in the context of the continuum model allows us to be prescriptive in setting restoration goals. Enforcing the discipline of explicit objectives, with restoration expectations described in terms of predicted values of functions, causal mechanisms and temporal response trajectories, will hasten the development of meaningful criteria for restoration success. Given our objective of restoring bottomland hardwood forest ecosystems, one criterion for success should be the establishment of forested conditions, i.e., canopy closure. Landowners should be given opportunities to pursue more intensive restoration techniques. Long-term maintenance and aftercare, and enhancement opportunities should be given greater attention when planning restoration projects. For most restoration projects, the afforestation stand will be an initial step along a path toward a naturally self-renewing forest. The time it takes to traverse that path will be determined by the willingness of landowners or taxpayers to pay the costs of more complete restoration.

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