Chapter 9

Restoring Forested Wetland Ecosystems

John A. Stanturf, Emile S. Gardiner, and
Melvin L. Warren Jr.

Forests as natural systems are intrinsically linked to the sustainability of freshwater systems. Efforts worldwide to restore forest ecosystems seek to counteract centuries of forest conversion to agriculture and other uses. Afforestation, the practice of regenerating forests on land deforested for agriculture or other uses, is occurring at an intense pace in the Lower Mississippi Alluvial Valley (LMAV) of the southern United States. Objectives of this chapter are (1) to place afforestation efforts in the LMAV into a global context of forest restoration by drawing parallels to work in other countries; (2) to summarize available information on afforestation techniques used to restore bottomland hardwood ecosystems; and (3) to document what is known about the effects on ecosystem functions. The dominant goal of all restoration programs in the LMAV, whether on public or private land, has been to create wildlife habitat and improve or protect surface water quality. Complex plantations that retain economic and logistic advantages of simple plantations can best meet some restoration goals. Complex plantations can include various arrangements of multiple species in true mixtures or intercropping mixtures. Potential benefits of mixed-species stands versus single-species stands can include increased pest resistance in the stand, increased productivity or yields if the stand is vertically stratified, increased product diversity, improved quality of crop trees, and increased canopy species diversity. Such healthy, diverse forests are critical to sustaining freshwater ecosystems. Riverine forests such as bottomland hardwoods and depressional swamp forests directly influence freshwater systems, and therefore restoration of these forests is considered essential to improving water quality.

Forests as natural systems are intrinsically linked to the sustainability of freshwater systems. Although commodity production from forests is a well-recognized beneficial use, the value and benefit of ecological linkages between forests, water resources, and humans may not be obvious to the casual observer. Forests play critical roles in moderating extremes in discharge from streams and rivers (e.g., increased flows in drought, decreased flows in floods) and are important in recharge of groundwaters. Forest cover decreases erosion and filters, stores, and moderates nutrient release into streams and rivers. Large wood from forests plays a major ecological role in the functioning of stream, river, and estuarine systems by forming and stabilizing channels, providing fish and aquatic organism habitat, and increasing productivity. Forest cover is often at the heart of the debates about global climate change, and the effect of reduced forest cover on climate has direct implications for the quantity and quality of worldwide freshwater supplies. Reestablishment of forests is a primary component of a holistic approach to worldwide sustainability of freshwater ecosystems.

Efforts worldwide to restore forest ecosystems seek to counteract centuries of forest conversion to agriculture and other uses (Stanturf2002). Forest restoration in the broad sense is widespread, although there is no agreement on what constitutes restoration. Market forces, changing trade policies, and agricultural incentive programs drive conversion of cleared land back to trees. Afforestation, the practice of regenerating forests on land deforested for agriculture or other uses, is occurring at an intense pace in the LMAV of the southern United States. Objectives of this chapter are to (1) place afforestation efforts in the LMAV into a global context of forest restoration by drawing parallels to work in other countries; (2) summarize available information on afforestation techniques used to restore bottomland hardwood ecosystems; and (3) document what is known about the effects on ecosystem functions.

Forest Restoration Concepts

Restoration generally connotes transition from a degraded state to a former “natural” condition. All restorative activities described (reforestation, rehabilitation, afforestation, and reclamation) have been called forest restoration, but none of these would qualify as true restoration to the purist (Bradshaw 1997; Harrington 1999). In the narrowest interpretation, restoration requires a return to an ideal natural ecosystem with the same species diversity, composition, and structure of a previous ecosystem (Bradshaw 1997) and as such is probably impossible to attain (Cairns 1986). Pragmatically, a broad definition of forest restoration would include situations where forest land use as well as land cover are reestablished (afforestation or reclamation) or where a degraded forest is returned to a more “natural” condition in terms of species composition and stand structure (rehabilitation). This is the approach adopted in this chapter (for a more detailed discussion, see Stanturf and Madsen 2002).

Examples of forest restoration abound (Table 9.1) and those in northern

Table 9.1. Examples of forest restoration efforts in various parts of the world

Type of restoration	*Region*	*Former condition*	*Restored condition*
Afforestation	Lower Mississippi Alluvial Valley, United States’	Agriculture	Bottomland hardwoods
Afforestation	Nordic countries’	Agriculture	Hardwoods, sometimes Norway spruce
Afforestation	Tropical countries[3]	Agriculture	Exotic and native hardwoods
Afforestation	Venezuela	Cerrado	Caribbean pine
Afforestation	Iceland[4]	Eroded grazing land	Birch, lupine/birch
Reclamation	Everywhere	Mined land	Various
Reclamation	Asia[5]	Shrimp ponds	Mangrove
Reclamation	Ireland	Mined peatland	Sitka spruce, various hardwoods
Reclamation	India’	Saline and sodic soils	Eucalyptus species, acacia species, other native species
Rehabilitation	Southeastern United States’	Loblolly pine Plantations	Longleaf pine Woodlands
Rehabilitation	Interior highlands, southeastern United States	Shortleaf pine/hardwood forests	Shortleaf pine/bluestem grass woodlands
Rehabilitation	Northern Europe’	Norway spruce plantations	Oak or beech woodlands
Rehabilitation	England and Scotland	Spruce or pine plantations	Mixed woodlands

‘Allen 1997; Gardiner et al. 2002; Hamel er al. 2002; Newling 1990; Savage et al. 1989; Schweitzer et al. 1997; Sharitz 1992; Stanturf et al. 1998, 2000, 2001; Twedt and Portwood 1997; Twedt et al. 1999.

‘Madsen et al. 2002.

‘Knowles and Parrotta 1995; Lamb and Tomlinson 1994; Parrotta 1992; Parrotta et al. 1997.

‘Madsen et al. 2002.

‘Burbridge and Hellin et al. 2002.

‘Whalley 1988.

Walker and Boyer 1993.

‘Madsen et al. 2002.

Europe illustrate the diversity of conditions that may occur (Madsen et al. 2002). Nordic forests provide diverse examples of afforestation and rehabilitation. In Iceland, afforestation on barren and degraded land aims to restore birch (*Betula* spp.) woodlands, which covered more than 25 percent of the land area at the time of settlement in the tenth century (Aradottir and Arnalds 2001). In contrast, afforestation in other Nordic and Baltic countries occurs on fertile farmland. Even so, the aims of afforestation differ between these countries. In Finland, Sweden, and Norway, afforestation is limited to replacing small-scale, inefficient agriculture. In Estonia, the post-communist government has returned agricultural property to descendants of the former landowners. Many of these "new" landowners lack knowledge or experience with agronomy. Thus, forestry may provide these landowners with a low-cost land-use alternative. The afforestation program in Denmark emphasizes sustainability, nature conservation, and biodiversity; with provisions to protect groundwater, improve recreational value of the landscape, and reduce agricultural subsidies (Madsen et al. 2002). The Danish government intends to double the nation's forested area within one tree rotation, about 100 years.

Forestry in the Nordic countries traditionally has emphasized conifer management for sawtimber and pulp. Conifers are favored because of their high productivity and low cost of establishment. Concerns for ecological sustainability, nature conservation, and sustainable land use have risen over the past two decades, while prices for softwood timber have fallen. Additionally, some conifer species are prone to windthrow on certain sites. These problems have increased the interest of landowners in managing broadleaf species and natural regeneration practices (Larsen 1995). Broadleaf tree species are being considered for afforestation of former agricultural land and for conversion (rehabilitation) of conifer plantations on better soils in Denmark, southern Sweden, Germany, the United Kingdom, and the Republic of Ireland (Table 9.1).

The Lower Mississippi Alluvial Valley Context

The Lower Mississippi Alluvial Valley has undergone the most widespread loss of bottomland hardwood forests in the United States. Besides the extensive loss of forest cover by clearing for agriculture, regional and local hydrologic cycles were changed drastically by flood-control projects that separated the Mississippi River and its tributaries from their floodplains (Sharitz 1992; Shankman 1999; Stanturf et al. 2000). The LMAV is regarded as one of the most endangered ecosystems in the United States (Noss et al. 1995; Abel1 et al. 2000). Bottomland systems across the southern United States provide habitats for breeding populations of Neotropical migratory birds as well as staging grounds for these birds during migration. The southern United States is at risk for significant loss of aquatic diversity, particularly native fishes, freshwater mussels, and crayfishes (Williams et al. 1993; Taylor et al. 1996; Warren et al. 2000). The U.S. Environmental Protection Agency (U.S. EPA) has identified the Yazoo-Mississippi basin as an area of significant concern for surface- and groundwater quality (U.S. EPA 1999). In response to concerns for wildlife habitat and water quality protection, the LMAV has been targeted for the most extensive forest restoration effort in the United States.

The Need for Restoration

Before European contact, bottomland hardwood forest occurred on 8.5 to 10.1 million hectares in the LMAV (The Nature Conservancy 1992), although actual forest cover may have been less because of agricultural use by Native Americans (Hamel and Buckner 1998). Fully 96 percent of subsequent deforestation in the LMAV has been by conversion to agriculture (MacDonald et al. 1979; Department of the Interior 1988). About one-half of the original forests were cleared between the early 1800s and 1935 (Fig. 9.1). Flood-control projects straightened and deepened rivers, drained swamps, and encouraged the extension of forest clearing to lower, wetter sites. The most recent surge in deforestation occurred in the 1960s and 1970s when rising world soybean (*Glycine max*)

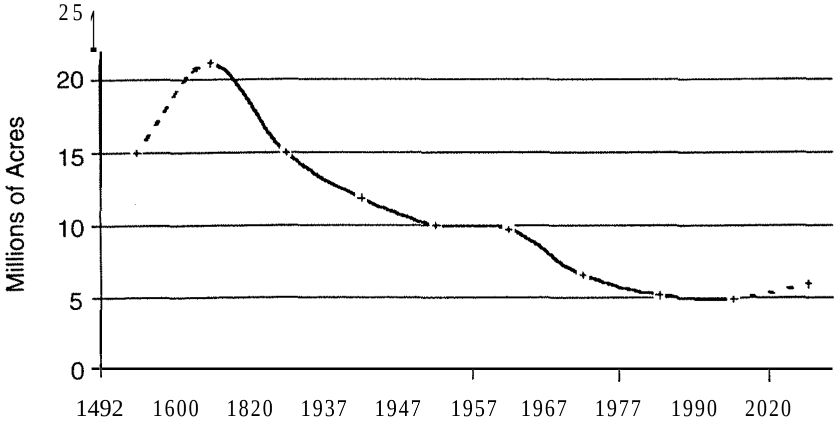

Figure 9.1. Extent of bottomland hardwood forests in the Lower Mississippi Alluvial Valley from pre-European contact (1492) to modern *times* (1990) with projections to 2020. The estimate of forest cover prior to European contact assumes that Native American agriculture was at least as extensive as early colonial agriculture around 1820. This is probably an underestimate. The prediction of the area to be restored by 2020 is 405,000 hectares, which is roughly double the amount planted through 2005. (Source: Stanturf et al. 2000)

prices made it profitable to convert additional area to agriculture (Sternitzke 1976). However, the passage of “Swampbuster” provisions in the 1985 Farm Bill has minimized further clearing of forested wetlands for agriculture (Shepard et al. 1998).

Restoration Practice

Actions on federal land and federal incentive programs drive restoration in the LMAV, although states also have restoration projects on public land (Savage et al. 1989; Newling 1990). The dominant goal of all restoration programs in the LMAV, whether on public or private land, has been to create wildlife habitat and to improve or protect surface water quality (King and Keeland 1999). In practice, this means afforestation of small areas (usually no more than 120 hectares) within a matrix of active agriculture. Although we know how to afforest many sites (Stanturf et al. 1998), recent experience with the Wetlands Reserve Program (WRP) in Mississippi illustrates the difficulty of applying this knowledge broadly (Stanturf et al. 2001). Currently, restoration on public and private land is planned for 200,000 hectares in the LMAV over the next decade (Table 9.2) but as much as 1 million hectares may be available (Stanturf et al. 2000).

Table 9.2. Forest restoration planned on former agricultural land by federal and state agencies in the Lower Mississippi Alluvial Valley, United States

		(ha)[1]		
Program	*Agency*	*199s*	***Planned to 2005***	***Total***
Wildlife refuges	U.S. Fish and Wildlife Service	5,174	10,004	15,178
Wetland mitigation	U.S. Army Corps of Engineers	2,024	9,704	11,729
State agencies	Mississippi, Louisiana, Arkansas	13,506	40,516	54,022
Wetlands Reserve Program (WRP)	Natural Resources Conservation Service[2]	53,021	47,773	100,795
TOTAL		73,725	107,997	181,724

Source: Adapted from Stantud et al. 2000.

‘Estimates furnished by participants at the workshop Artificial Regeneration of Bottomland Hardwoods: Reforestation/Restoration Research Needs, held May 11-12, 1995, in Stoneville, Miss.

‘Formerly, Soil Conservation Service.

Plantation Forestry as a Restoration Mechanism

It should be self-evident that the first step in restoring a forest is to establish trees, the dominant vegetation. Although this is not full restoration in the sense of Bradshaw (1997), it is a necessary step and far from a trivial accomplishment (Stanturf et al. 1998; Hamel et al. 2002; Stanturf et al. 2001). Nevertheless, many people object to traditional plantations on the grounds of aesthetics or lack of stand and landscape diversity. The correct ecological comparison, however, is between the forest plantation and intensive agriculture rather than between the forest plantation and a mature natural forest (Stanturf et al. 2001). All forest alternatives provide vertical structure, increased plant diversity, wildlife habitat, and environmental benefits. Kanowski (1997) argued for a dichotomy in concepts of plantation forests, between traditional industrial plantations established for fiber production and complex plantation systems established to maximize social benefits other than wood. Perhaps some restoration goals can be met better by developing a concept of complex plantations that retain economic and logistic advantages of simple plantations.

Characteristics of Simple Plantations

Simple plantations are single-purpose, usually even-aged monocultures that can produce up to ten times more wood volume than natural forests (Kanowski 1997). Simple plantations, nevertheless, provide multiple benefits when compared to alternatives such as continuous agriculture. For example, they may satisfy sustainability criteria (e.g., Santiago Declaration 1999) if managed well. Advantages of simple plantations include that they can be established with proven technology, their management is straightforward, and they benefit from economies of scale. Simple plantations may be preferred if financial return is the primary objective of a landowner (Stanturf et al. 2001). However, complex plantations that provide greater social benefit can be established at a reasonable cost. The additional cost may be as little as a 10 percent reduction in timber returns (Kanowski 1997) or at a net financial gain to the landowner (Stanturf and Portwood 1999).

Characteristics of Complex Plantations

Complex plantations diminish concerns associated with how the forest appears (aesthetics) and increase structural and compositional diversity. To optimize these effects, however, requires consideration of surrounding land uses and identification of the best method to establish a mixed-species stand given site conditions, economics, and desired future returns from the stand.

Association with Other Land Uses

Objections to forest plantations are often cast in terms of aesthetics. The "sharp" boundary between a plantation and other land uses is objectionable to some people, as is the uniformity of trees planted in rows. To integrate the plantation with other land uses, sharp edges can be "softened" by fuzzy or curved boundaries. Where plantations are established on small farm holdings, agroforestry systems such as intercropping can blend land uses. Additionally, forested riparian buffers can be established as plantations in agricultural fields. These plantation buffers can protect water quality by filtering sediment, nutrients, and farm chemicals, and they may reduce access by livestock to stream banks. Riparian buffers increase landscape diversity and can serve as corridors between patches of fragmented forests. In floodplain landscapes such as bottomland hardwoods, areas of permanently saturated or inundated soil (respectively, moist soil units and open water areas) are common and diversify the interior of plantations.

The uniformity of plantation rows can be overcome in several ways. Perhaps the simplest technique is to offset rows. Uniform spacing between rows and between seedlings within a row is common, resulting in a square pattern. Such a pattern is necessary only if required for post-planting operations such as disking, or if maximizing stocking is desired. Rows can be offset to produce a parallelogram instead of a square, or rectangular spacing can be used. Alternatively, plantations can be planned with a recreational viewer in mind so that the view from trails and roads is always oblique to the rows, thereby escaping notice. Still, once the canopy reaches sufficient height that ground flora and midstory plants can establish, many plantations take on the appearance of natural stands, at least to the casual observer. This is especially the case following manipulation of structure by thinning.

Species Composition and Vegetation Structure

A more serious objection to plantations is the lack of diversity in terms of species composition and vertical structure. Simple plantations typically are not as diverse as natural stands, at least for many years. Foresters have devised several methods to establish multiple-species stands. For example, planting several blocks of different species in a stand, or even alternate rows of different species, is possible and creates some diversity at the stand level. Distribution, however, remains more clumped than would be typical of a natural stand.

Other methods are available for establishing mixed-species stands. For example, nurse crops of faster-growing native species (Schweitzer et al. 1997) or exotics (Lamb and Tomlinson 1994) may be used to facilitate the establishment of slower-growing species. In this approach, there is no intention of retaining the nurse crop species through the rotation of the slower-growing species (this could also be termed *relay intercropping*). Although the nurse crop method has many advantages, and in the short-term provides species diversity and vertical structure, these characteristics may decline once the nurse crop is removed. The challenge is to develop methods for establishing several species in intimate group mixtures. Such methods must account for species growth patterns, relative shade tolerances, and competitive abilities to avoid excessive mortality during the self-thinning or stem exclusion stage of stand development.

Vertical structure is an important feature of forests for wildlife habitat (Twedt and Portwood 1997; Hamel et al. 2002). Early stages of stand development, whether in natural forests or plantations, are characterized by low light availability in the understory. In most restoration forests, understory and midstory development does not occur for many years, until overstory crowns differentiate. Annual disturbance while in agriculture depletes buried seed and rootstocks of native plants, and low light levels in the young forest preclude understory development from invaders. Land managers can intervene by planting understory species, but guidance on methods, planting density, or probable success rates is lacking. As indicated above, relay intercropping provides vertical structure for a portion of the rotation. Natural dispersal into gaps may encourage understory development, whether gaps are created by thinning or left during planting (Allen 1997). The critical factor limiting understory development by natural invasion is whether there are seed sources for understory plants within dispersal range (Johnson 1988).

Common Challenges in Restoration

The challenges of forest restoration in different countries are surprisingly similar (Kanowski 1997): overcoming site degradation and limitations, prescribing appropriate species, and applying cost-effective establishment methods. Three steps are key to planning forest restoration: (I) understanding current conditions (the given conditions, a starting point); (2) clarifying objectives and identifying an appropriate goal (the desired future condition); and (3) defining feasible actions that will move toward the desired condition. In most cases, the forester has several options for intervening, as there are multiple silvicultural pathways toward the desired future condition. The choice of intervention affects the financial cost, the nature of intermediate conditions, and the time it takes to achieve the desired condition. It is imperative that silvicultural decisions are made with clear objectives in mind and with an understanding of the probability that a particular intervention will be successful.

Overcoming Site Limitations

Site potential, and whether it has been degraded, sets limits on what can be achieved by intervention. refers to the combination of relatively unchanging physical factors that affect species composition and stand vigor. Soil and landform characteristics determine moisture availability, aeration, and fertility. In wetland forests, hydroperiod characteristics are important (flood frequency, seasonality, duration, and depth). Site potential is not immutable, however, and can be influenced positively or negatively by changes in land cover or land use. Existing forests in need of rehabilitation may have become degraded by past mismanagement such as timber high grading (i.e., removing only the biggest, most merchantable trees), suppression, or holding water late into the growing season in greentree reservoirs. In other cases, hydroperiod alterations, hurricanes, severe windstorms, floods, or insect outbreaks may degrade the stands but not usually the site. On the other hand, previous land use may have degraded site conditions, especially for afforestation and reclamation projects. Specific conditions may vary from soil erosion or salinization, in which soil chemistry and physical structure are inhospitable to native trees, to lowered fertility from continuous cropping, which slows or precludes tree growth. In some cases, land becomes available for restoration because the previous land use was unsustainable.

An extreme example of an unsuitable land-use practice leading to site degradation and creating the need for forest restoration can be found in the mangrove (*Rhizophora* spp., ***Avicennia*** spp., and others) forests of Asia (Burbridge and Hellin 2002). Aquaculture is an important source of income, employment, and exports in many of the world’s coastal regions. Extensive aquaculture has been a sustainable part of coastal land and water use for many centuries in Asia. The rapid expansion into mangrove forests of semi-intensive and intensive shrimp aquaculture, often poorly planned and managed, has created significant adverse environmental, economic, and social effects. Unnecessary destruction of coastal wetland forests for nonsustainable aquaculture production has occurred in extensive areas of many of the poorer developing nations such as India, the Philippines, and Indonesia (Burbridge and Hellin 2002). Following abandonment of fishponds, because of acid sulfate potential soils, reclamation projects are necessary to restore mangrove forests (Burbridge and Hellin 2002).

Human-induced disturbances are overlain on the natural disturbance regime in the landscape. Coastal Plain swamp forests of the southern United States, for example, exist with windstorms as normal, episodic events (Conner et al. 1989). Recent hurricanes such as Hugo (in 1989) in the southeastern Atlantic Coastal Plain and Andrew (in 1992) in the northern Gulf of Mexico caused extensive damage to forests in their paths. Such damage may be especially severe to shallow-rooted hardwoods with large crowns that are common on alluvial floodplains. Regeneration in hurricane-damaged areas may be limited if natural hydrological patterns have been altered.

Rehabilitation problems in swamp forests dominated by baldcypress (*Taxodium* ***disticbum)*** and water tupelo (*Nyssa* ***aquatica)*** or Atlantic white-cedar

(*Chamaecyparis thyoides*) illustrate the critical constraint imposed by hydroperiod (Conner and Buford 1998; Conner et al. 2002). Floodplain communities are adapted to a predictable flood pulse, and alteration of the timing, duration, or magnitude of this flooding reduces diversity and productivity (Junk et al. 1989). Human activities have inextricably altered the hydrologic regime of most alluvial floodplains in the United States (Dynesius and Nilsson 1994; Poff et al. 1997; Shankman 1999). Dams reduce the frequency, magnitude, and flashiness of downstream flooding, often extend the length of time the floodplain is inundated, and may change seasonality of peak flows, reduce the rates of erosion and sedimentation (in silt-laden systems). Channelization and canal building, with associated levees or spoil banks, often impound water permanently over large areas of swamplands (Conner et al. 1989). Because many swamp areas are permanently to nearly permanently flooded, natural regeneration is negligible (Conner et al. 1989), and planting is difficult.

Another aspect of flooding that should be considered for coastal swamp forests in the United States is sea-level rise and resulting increases in salinity (Conner and Brody 1989). Although baldcypress and water tupelo can survive extended and even deep flooding (Hook 1984), they seem incapable of enduring sustained flooding by water with salinity levels greater than 8 parts per thousand (McLeod et al. 1996). Atlantic white-cedar is another coastal species that is very intolerant of salinity.

The cause of site or stand degradation should be identified and whether the degradation is still occurring should be noted. For example, alteration of a site by changed hydroperiod poses several questions. Can the hydroperiod be restored or the effects of alteration somehow be mitigated? Should the restoration effort target a vegetation assemblage adapted to present hydroperiod and site conditions? Hydroperiod alterations caused by flood-control projects, dams, or highway construction tend to be irrevocable, at least in the short term. Flooding caused by beaver ***(Castor canadensis)*** dams, however, can be reduced by removing the dam, but continued management of beaver population levels will be required to avoid recurring problems. The guiding principle for the forester should be to rehabilitate or restore in accordance with existing conditions, unless alteration is feasible, affordable, and within the control of the forester.

Appropriate Species

Most restoration efforts favor the use of native species, although there are situations where exotic species are preferred. In the tropics, population pressures and land scarcity may require that restoration include species that provide early economic returns (Parrotta 1992), and native forest species may be unsuited for degraded sites. Fast-growing exotic species can be used to alter site conditions enough for native species to thrive (Knowles and Parrotta 1995; Parrotta et al. 1997).

The perceptron of what constitutes "native" species or communities may be contentious. Some fast-growing species may be native but considered undesirable by portions of the public or by agencies. For example, some hold an aversion to planting pine (especially loblolly pine, *Pinus taeda*) rather than broadleaves in the southern United States, and some disapprove of planting eastern cottonwood (*Populus deltoide*.)in the LMAV. Furthermore, species on the approved list for afforestation programs may be native to the area but not to the particular site. In the LMAV, for example, extensive hydrologic changes have allowed planting of oak (*Quercus* spp.) in greater proportion than is thought to have been in the forests prior to European settlement (Fig. 9.1). Even documenting the composition of the pre-disturbance forested landscape can be difficult and contentious (Hamel and Buckner 1998; Stanturf et al. 2001).

A wide array of edaphic and hydrologic conditions sculpted by the erosional and depositional processes of rivers provides the foundation for high species richness and spatial diversity of vegetation communities in alluvial floodplains. Site types range from permanently inundated sloughs with very poorly drained, heavy clay soils to rarely inundated ridges of well-drained, sandy loams (Stanturf and Schoenholtz 1998). Associations of tree species with the various site types have been well established since the early 1900s (Putnam et al. 1960; Meadows and Nowacki 1996). Thus, it follows that initial and long-term afforestation success, trajectory of stand development, site productivity, and future management opportunities and costs will be determined largely by the suitability of the species assigned to a given site.

An open question is, to what extent should the manager today consider the possible effects of global climate change in choosing appropriate species to plant. Global Circulation Models used by policy-makers yield very different results for the southern United States at the scale of the forest stand. Nevertheless, managers contemplating long rotations may want to hedge their bets on upland sites by planting species adapted to drier conditions. In bottomlands, the situation is more complicated. Projected rising sea level will not only inundate coastal forests but also cause a rise in the base level of rivers in the region, changing the hydrologic regime of many sites.

Effective Establishment Methods

Choosing species appropriate to the site and management objectives of the landowner is an important first step in restoration. Choice of stock type and proper handling are important as well as adequate site preparation and post-planting practices such as weed control. High survival is needed to ensure adequate stocking (seedling densiry) and to minimize costs, especially where seedling costs are high (e.g., Scandinavia; Madsen et al. 2002). Survival rates in industrial plantations set the benchmark and are commonly 80 percent to 90 percent. However, it may be unreasonable to expect such high survival in many restoration programs (King and Keeland 1999), because the knowledge base may be insufficient due to limited research, lack of practical experience, or untrained available labor (Gardiner et al. 2002).

Benefits of Restoration

The benefits of restoration usually are identified in terms of agency priorities or social benefits; seldom are the diverse objectives of landowners recognized. In most market economies where rights and obligations of ownership rest with private landowners, what is appropriate for public land may not be the most attractive restoration option for private landowners (Stanturf et al. 2001; Stanturf and Madsen 2002). Nevertheless, there can be considerable overlap in the expected benefits to society and the affected landowner. The array of possible landowner objectives can be illustrated with a limited set of management scenarios from the LMAV (Table 9.3). For simplification, three scenarios are presented: short-rotation management for pulpwood or fuelwood; a longer-rotation typical of management for sawlog production which is suitable for wildlife that requires complex vertical structure, such as certain Neotropical migratory songbirds (Hamel et al. 2002); and an option termed "green vegetation," which is essentially the no-management scenario. In the green vegetation scenario, species composition and stand structure

Table 9.3. Financial, recreational, and environmental benefits expected from three afforestation scenarios common in the Lower Mississippi Alluvial Valley, United States

	Expected benefit level					
	Financial		*Recreational*		*Environmental*	
Scenario	*Short-term*		***Hunting***	***Nonconsumptive***	***Conservation practices***	***Land retirement***
Short rotation (pulpwood, fuelwood)	High	High	High	Medium	Medium	No
Long-rotation (timber, wildlife)	Medium	High	High	High	High	Medium
Green vegetation	Low to no	No	Low	Medium	Medium	High

are secondary concerns to removing land from active agriculture. This option meets the objectives of federal programs such as the WRI? (Stanturf et al. 2001). It may also provide habitat conditions for certain wildlife species typical of old fields that otherwise would not occur on the landscape (Hamel et al. 2002).

Benefits comprise financial, recreational, and environmental outcomes. Because cash flow is important to many landowners, and the adjustment from annual to periodic income is often cited as a barrier to afforestation, financial benefits are considered to be both short term and long term. Recreational benefits include hunting (typically for white-tailed deer [*Odocoileus virginianus*], wild turkey [*Meleagris gallopavo*], and waterfowl) and nonconsumptive benefits such as bird watching or hiking. Environmental benefits are separated into conservation practices (such as those installed to control soil erosion, protect water quality, or enhance wildlife habitat) and land retirement, where there is no ongoing management activity.

Financial Benefits

Financial returns from active management are substantial relative to the green vegetation scenario. Sawlog rotations of high-value oak and green ash (*Fraxinus pennsylvanica*) are expected within sixty to eighty years, with the first commercial thinning beginning in twenty to thirty years. Short-term financial returns from growing pulpwood-sized eastern cottonwood in the LMAV are realized within ten years of afforestation (Stanturf and Portwood 1999). Short-term financial returns are low from plantations of other species. Nevertheless, other species can be combined with cottonwood in the nurse-crop technique to produce income for one or two pulpwood rotations, hence the medium rating. The green vegetation scenario, typified by WRP plantings, provides no long-term income because timber management is unlikely, given the understocked stands that will develop (Stanturf et al. 2001). In the short term, there is income from the one-time easement payment made to the landowner (Stanturf et al. 2000).

Some landowners can realize other income from hunting leases and potentially from carbon sequestration payments. In the Mississippi portion of the LMA.. hunting rights are leased for $7.50 to $12.35 per hectare per year. There is also a potential for substantial income to landowners from credits from carbon sequestration (Barker et al. 1996). Although there is considerable uncertainty over accounting for carbon credits in national and international discussions (e.g., the Kyoto Protocol), there seems to be agreement that afforestation will be eligible for offset credit (Schlamadinger and Marland 2000). Current projections in the United States for the value of a carbon credit are on the order of $2.72 to $4.54 per megagram of CO, sequestered, but the value is much higher in Europe. Estimates from economic models suggest that a carbon tax of $27 to $109 per megagram of CO, would be necessary to stabilize global emissions at the 1990 level (Solberg 1997). Under these conditions, growing biomass for fuel would become an attractive alternative to fossil fuel and landowners in the LMAV may want to optimize carbon sequestration and biofuel benefits by planting black willow (*Salix nigra*) on soils too wet for eastern cottonwood.

Recreational Benefits

The primary recreational benefits assumed in the examples are from creating and enhancing wildlife habitat. Not all wildlife species require the same kind of habitat, so for simplicity the expected benefits can be separated into recreational hunting by the landowner (rather than lease fees) and nonconsumptive wildlife activities, such as bird watching or simply the existence value of wildlife to the landowner. Most species hunted in the LMAV benefit from a range of forest conditions, and expected benefits are high in stands managed for pulpwood or sawlogs. Low expected value is derived from the kind of open stands likely to develop from the green vegetation scenario (Allen 1997; King and Keeland 1999). Neotropical migratory birds and other birds are not uniform in their habitat requirements (Hamel et al. 2002), but some will benefit from the kind of early successional habitat typical of short-rotation stands (Twedt and Portwood 1997) as well as early successional herbaceous fields of the green vegetation scenario. Species of concern are of two kinds: those requiring early successional herbaceous vegetation and those found in the kind of complex vegetation structure found only in older stands, which the sawlog rotation may develop in time (Hamel et al. 2002). Birds that use intermediate conditions of stand development are likely to occur in developing stands for which the intended management purpose is sawtimber production.

Environmental Benefits

Water-quality benefits of afhorestation accrue from reducing soil erosion (Joslin and Schoenholtz 1998), and filtering, retaining, and assimilating nutrients and farm chemicals from surface runoff and groundwater (Huang et al. 1990). Among key wetland functions, biogeochemical processes such as filtration have the highest societal value. This function requires flow-through hydrologic regimes typical of riverine forests. However, typical afhorestation stands in the LMAV are not subject to the flow-through hydrologic pulse of a riverine system, and their ability to filter nutrients will be limited (Lockaby and Stanturf 2002).

Afforestation of former agricultural areas that are protected from flow-through systems (i.e., flooding) by dikes, ditches, and other barriers cannot be considered restoration in a complete sense unless some semblance of flow-through processes are also restored. Large-scale restoration of natural, riverine flooding regimes is rarely feasible. This limitation of afforestation activities has been recognized previously (Allen 1997; King and Keeland 1999). Suggested remedies have included plugging drainage ditches or building water-control structures on portions of the afforested sites so that controlled flooding can be induced in much the same way that it is applied within greentree reservoirs. On public land such as national wildlife refuges and national forests, relatively large areas have been restored in this fashion as greentree reservoirs, moist soil management units, or permanent water bodies. In addition, it is common for some flooding to occur on lower-lying portions from accumulation of precipitation. Although afforested sites may have water-control structures that produce standing water and appear to function as depressional wetlands, they differ significantly from basin wetlands in their functioning (Lockaby and Stanturf 2002). Because these quasi-depressional afforested systems remain isolated from riverine influences, they contribute little to biogeochemical filtering or to the export of particulate or dissolved organic carbon to aquatic systems.

Improved water quality can be derived from forested riparian buffers. Planted forested buffer strips in an agricultural landscape are uncommon, although several studies have shown that buffer strips are effective in removing soluble nitrogen and phosphorus (up to 99 percent) and sediment (Comerford et al. 1992). The efficiency of pesticide removal by forested buffer strips has been examined in some environmental fate studies, which concluded that buffer strips 15 meters or wider were generally effective in minimizing pesticide contamination of streams from overland flow (Comerford et al. 1992). Recently, forested buffer strips in the LMAV became attractive financially to the landowner by a new incentive program (Continuous Signup/Conservation Reserve Program), which allows landowners to plant fast-growing plantation species, including eastern cottonwood.

The Environmental Protection Agency has identified the Yazoo-Mississippi basin as an area of significant concern for surface and groundwater quality. Although surface water runoff in the LMAV contributes only 20 percent of the nitrate loading implicated in the expansion of the hypoxic zone in the Gulf of Mexico, the EPA is expected to focus significant resources on the LMAV to improve water quality. Policy alternatives under consideration include reducing nitrogen use by 20–40 percent and converting agricultural land to forests in an effort to restore and enhance natural denitrification processes (U.S. EPA 1999). The assumption is made that restoration (afforestation) of bottomland hardwood forests will reduce nutrient export into the Gulf. This will be true to the extent that changing land use from row crop agriculture to forests will reduce a potential source of nutrients (Thornton et al. 1998). However, the restored system will play at most a small role as a nutrient filter unless it is hydrologically linked to a riverine system. Thus a greater benefit, in terms of nutrient filtration, would come from afforestation of the active floodplains of small rivers throughout the basin, and from buffer strips planted along drainage ways (Castelle and Johnson 2000). Nevertheless, the relative effectiveness of forest versus grass buffers in nutrient filtration remains uncertain.

Effects of Restoration on Wildlife and Fish

Afforestation is assumed to benefit "wildlife" (Wesley et al. 1981; Weaver et al. 1990; Cannell 1999b). On the other hand, certain native wildlife and grazing animals can hinder afforestation efforts (e.g., Houston 1991). Recent assessments of afforestation of agricultural lands in the LMAV have stressed the importance of rapidly attaining the physical structure and stature of forests (Schweitzer et al. 1997). Such rapid afforestation implies rapid accumulation on the landscape of the physical structure and stature of forest. Rapid development of vertical forest structure is implicit in the environmental (Joslin and Schoenholtz 1998) and economic (Scholtens 1998) analyses of afforestation. Rapid afforestation is also an essential feature of programs directed toward carbon sequestration benefits (Cannell 1999a).

Afforestation, particularly rapid afforestation, is likely to shorten the early successional period. Herbaceous-dominated plant communities appropriate for wintering birds utilizing early successional habitats consequently will persist for shorter periods if land is afforested rather than allowing natural succession. Rapid afforestation provides winter habitat for a number of species quickly (Wesley et al. 1981; Twedt and Portwood 1997) at the expense of a few high-priority species found in early successional habitats. Less-rapid restoration of forests in the LMAV may provide demonstrable, albeit unintended, benefits to birds that winter within afforested sites in early successional stages. The early successional species that specialize on herbaceous vegetation are of higher-than-average conservation priority among the birds found in afforestation areas (Hamel et al. 2002).

Forested stream buffer zones provide multiple benefits to stream fishes (Angermeier and Karr 1984; Gregory et al. 1991). Indirect benefits include reduction of sediment and nutrient inputs (Lowrance et al. 1984), stabilization of stream banks, and moderation of water temperature extremes (Gregory et al. 1991), all factors that can affect fish productivity, physiology, reproduction, and community composition (Matthews 1987). More directly, organic matter input into streams as leaves and instream wood provides the primary energy source for aquatic macroinvertebrates (Wallace et al. 1997), which form the food base for most stream fishes. In sandy Coastal Plain streams, debris dams and large wood greatly increase macroinvertebrate production (Benke et al. 1984, 1985; Smock et al. 1989), promote channel stability, and increase habitat complexity for fishes (Shields and Smith 1992). Even modest densities of instream wood in channelized or incised, sand-bed streams can shift fish communities from those associated with colonizing stages to those of intermediate or stable stages (Warren et al. 2002).

Many fishes of the southern United States use inundated forests for spawning, nursery, and foraging areas (Finger and Stewart 1987; Baker et al. 1991; Killgore and Baker 1996; O'Connell 2000). As in planting prescriptions for afforestation, hydrology is critical for fishes (Finger and Stewart 1987; Hoover and Killgore 1998). Long-duration flooding in late winter to early spring is especially important for spawning but even short-term flooding of forests can provide fishes with important energy from aquatic and terrestrial invertebrates (O'Connell 2000). Flooded forests provide nursery habitat to both wetland fishes and those of streams and rivers (Killgore and Baker 1996; Hoover and Killgore 1998). In the LMAV, flooded forest habitats support higher larval fish abundance of sport, commercial, and nongame fishes than flooded agricultural fields (recently cropped and fallow) (Hoover and Killgore 1998).

Large-scale afforestation of the LMAV emphasizing flood-prone agricultural areas and stream buffer zones could dramatically affect productivity and diversity of fish and other aquatic communities (Junk et a1.1989; Smock 1999). Within the LMAV, seasonally inundated forest habitat is greatly diminished (Hoover and Killgore 1998), most stream and river systems are highly modified (Shankrnan 1999), and most streams lack forested buffer strips. Nevertheless, southern bottomland hardwood wetland habitats support at least forty-five characteristic fish species (Hoover and Killgore 1998) and in drainages dominated by bottomland forest, most stream and river fishes occur in and actively use inundated forest habitat (Baker et al. 1991). As noted, afforestation in the LMAV now emphasizes small low-lying tracts embedded in a matrix of agriculture. Future emphasis on forested riparian stream buffer strips that connect stream and river systems to afforested tracts is a primary consideration to maintain and enhance fish and aquatic communities (Gore and Shields 1995).

Conclusion

The LMAV is currently experiencing extensive afforestation of former agricultural fields on sites that historically have supported bottomland hardwood forests. The current pace of afforestation may be maintained through the next decade, resulting in the establishment of hundreds of thousands of hectares of bottomland hardwood plantations. Hardwood plantations established on former agricultural fields in the LMAV comprise a diverse suite of plantation types ranging from single-species to mixed-species plantings. Single-species plantations, or monocultures, are often the most efficient plantation type for optimizing production of a single output, for example, fiber production or soil amelioration. In the LMAV, the native "soft" broadleaf species that exhibit indeterminate growth patterns are well suited for culturing in this manner. Eastern cottonwood plantations, which are cultivated for high-quality, printing fiber, are the most extensive example of single-species plantations cultivated in the LMAV. Single-species plantations are not well suited for production of high-quality sawtimber because most valuable species such as the oaks generally develop their highest vigor and quality in stands providing interspecific competition.

Mixed-species plantations can include various arrangements of multiple species in true mixtures or intercropping mixtures. Potential benefits of mixed-species stands versus single-species stands can include increased pest resistance in the stand, increased productivity or yields if the stand is vertically stratified, increased product diversity, improved quality of crop trees, and increased canopy species diversity (Smith 1986). True mixtures generally consist of randomly or systematically assigned species combinations established at the same time. Some mixed plantations are established with species of similar growth rates and developmental patterns, but most successful mixtures require establishment of species that will stratify within the forest canopy (Smith 1986; Clatterbuck et al. 1987). Stand development processes in well-designed species mixtures will track development patterns observed in natural mixed stands (Lockhart et al. 1999). Most current afforestation practices under governmental cost-share programs attempt to establish true species mixtures as a means of providing stand-level species diversity. Unfortunately, many of these plantations are established without consideration for the developmental trajectories and competitive interactions of the individual species comprising the mixed plantation and probably will not meet diversity objectives.

Scientists and land managers working in the LMAV have developed an intercropping scheme using the early successional eastern cottonwood as a nurse species for the slower-growing, disturbance-dependent Nuttall oak (Schweitzer et al. 1997; Twedt and Portwood 1997). Potential benefits of the eastern cottonwood-Nuttall oak (Q. *nuttallii*) intercropping could include rapid rehabilitation of soil quality, rapid development of vertical structure for animal habitat, early financial return on the restoration investment, and development of a favorable understory environment for establishment of oak seedlings and other native woody species. Intercropping systems show great potential for providing multiple ecological and landowner benefits in the LMAV.

Understandably, afforestation efforts have concentrated on establishing the dominant-forest overstory trees, and little is known about the development of understory plants (Stanturf et al. 2000). In addition to vegetative restoration, there may be a need to restore microtopography, especially in areas where the original ridge and swale topography was leveled for agriculture. This is an expensive proposition (King and Keeland 1999) and as yet the actual benefits of these practices are unknown. Nevertheless, such efforts would increase species diversity and result in restoration that is more complete.

Recommendations

Healthy forests are critical to sustaining freshwater ecosystems. Upland forests protect aquatic resources by damping the energy of raindrops and holding soil in place. Riverine forests such as bottomland hardwoods and depression4 swamp forests directly influence freshwater systems, and therefore restoration of these forests is considered essential to improving water quality. A successful restoration project should be designed to restore ecological functions as quickly as possible. The following seven criteria provide a guide to successfully restoring bottomland hardwood and swamp forests:

- Restoration objectives should be clearly stated. Not only should the end conditions of restoration success be stated at the outset, but also cost constraints should be recognized, the acceptable time interval identified, and any limitations on intermediate conditions clarified. If objectives are cast in terms of the range of functions that will be restored, then the mechanisms that will produce the successful endpoints should be identified (Stanturf et al. 2001).
- Develop an adequate understanding of present site conditions. At a minimum, this would include current hydroperiod for the previous five years, adjacent land uses that might affect soil limitations and hydroperiod.
- Design a restoration and management plan that will achieve the stated objectives within an acceptable time frame and at an acceptable cost. There is no substitute for expertise and experience in this step, and a bit of art is required as well (Allen et al. 2001; Gardiner et al. 2002; Hamel et al. 2002).
- Invest in high-quality planting material of species appropriate to site conditions (Allen et al. 2001; Gardiner et al. 2002).
- Invest in adequate site preparation for the objectives. If cost is an overriding constraint, then low-intensity methods may be appropriate (disk, plant or direct seed, walk away), although compensating for low survival by planting more seedlings of hardy species such as Nuttall oak may be necessary. If objectives such as high biodiversity are primary and cost is a secondary consideration, then interplanting cottonwood and oaks will meet objectives quicker.
- Supervise planting and check for proper handling and planting (Allen et al. 2001). A good safeguard is to specify in the planting contract what constitutes an adequate seedling ($^3/_8$-inch root collar diameter and a minimum of three lateral roots seems adequate) and acceptable planting practice. Build in penalties, as well as incentives, based on random inspection of the planting job while in progress.
- Apply post-planting cultural practices in a timely fashion, such as weed control or longer-term stand treatments such as thinning, if they are necessary to achieve objectives.

Much is known about forest restoration, at least in terms of establishing the dominant forest overstory species. Extension of current knowledge or application of conservation principles will be sufficient for many situations. Additional research, focused on improving economic efficiency and more fully restoring ecological functions, will be needed. We see five fundamental areas of vital importance for future research:

- Restoration systems need to be developed that will meet landowner objectives. By systems we mean packages of proven techniques for optimizing benefits at reasonable costs and with low risk of failure.
- In restoration of forested wetlands such as those in the Lower Mississippi Alluvial Valley, guidelines are needed for stock size and qualities that are species specific and well correlated to out-planting performance.
- Protocols are needed for transfer of genetic material. These exist for the commercial conifers but are surprisingly lacking for broadleaves. These will need to be ecotype specific, as well as by latitude and distance.
- New restoration systems are needed that produce an array of benefits quickly and are cost effective. We think the concept of complex plantations needs to be explored more generally.
- What constitutes restoration success should be defined for specific ecosystems, for an array of site conditions and management objectives, within a temporal framework. The essential question is, "What should the landowner expect on a site after a stated time period, given the level of investment in restoration?"

Forest restoration, in the broad sense, is widespread. Similar challenges face foresters attempting large-scale restoration, and there are no easy answers. Simply put, the questions are what to do, how to do it, how to pay for it, and what benefits can we expect? Several fundamental components of afforestation are generally lacking in most regeneration practices currently performed in the LMAV. Developing some of these missing components will require additional research, but others will require only an extension of current knowledge or application of conservation principles. Incorporating silvicultural and ecological principles into public and private restoration activities will provide landowners, natural resource managers, and the general public better methods for evaluating success of these afforestation activities and should improve afforestation efficiency, ecosystem health, and resource sustainability.

References

Abell, R. A., D. M. Olson, E. Dinerstein, I? T. Hurley, J. T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C. J. Loucks, and I? Hedao. 2000. *Freshwater ecoregions of North America: A conservation assessment.* Washington, D.C.: Island Press.

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

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 SRS40, Lafayette, La.

Angermeier, I? L., and J. R. Karr. 1984. Relationship between woody debris and fish habitat in a small warmwater stream. *Transactions of the American Fisheries Society* 113:716–726.

Aradottir, A. L., and 0. Arnalds. 2001. Ecosystem degradation and restoration of birch woodlands in Iceland. Pp. 293–306 in *Nordic mountain birch ecosystems,* edited by F. E. Wielgolaski. Carnforth, U.K.: UNESCO, Paris and Parthenon Publishing.

Baker, J. A., K. J. Killgore, and R. L. Kasul. 1991. Aquatic habitats and fish communities in the Lower Mississippi River. *Aquatic Sciences* 3:3 *13-356.*

Barker, J. R., G. A. Baumgardner, D. I? Turner, and J. J. Lee. 1996. Carbon dynamics of the conservation and wetland reserve programs. *Journal of Soil and Water Conservation* 51:340–346.

Benke, A. C., R. L. Henry III, D. M. Gillespie, and R. J. Hunter. 1985. Importanceof snag habitat for animal production in southeastern streams. *Fisheries* 10(5):8–13.

Benke, A. C., T. C. Van Arsdall Jr., D. M. Gillespie, and F. K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: The importance of snag habitat and life history. *Ecological Monograph* 54:25–63.

Bradshaw, A. D. 1997. What do we mean by restoration? Pp. 8-14 in Restoration *ecology and sustainable development,* edited by K. M. Urbanska, N. R. Webb, and I? J. Edwards. Cambridge: Cambridge University Press.

Burbridge, P. R., and D. C. Hellin. 2002. Rehabilitation of coastal wetland forests degraded through their conversion to shrimp farms. Pp. *20-29* in *Proceedings of a Conference on Sustainability of Wetlands and Water Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Cairns, J., Jr. 1986. Restoration, reclamation, and regeneration of degraded or destroyed ecosystems. Pp. 465–484 in *Conservation biology* edited by M. E. Soule. Ann Arbor, Mich.: Sinauer Publishers

Cannell, M. G. R. 1999a. Forests, Kyoto, and climate. *Outlook on Agriculture* 28(3): 171-177.

———. 1999b. Environmental impacts of forest monocultures: Water use, acidification, wildlife conservation, and carbon storage. New *Forests* 17(1/3): 239-262.

Castelle, A. J., and A. W. Johnson. *2000. Riparian vegetation effectiveness.* Technical Bulletin No. 799, National Council of the Paper Industry for Air and Stream Improvement, Inc., Research Triangle Park, N.C.

Clatterbuck, W. K., C. D. Oliver, and E. C. Burkhardt. 1987. The silvicultural potential of mixed stands of cherrybark oak and American sycamore: Spacing is the key. *Southern Journal of Applied Forestry* 11: 158–161.

Comerford, N. B., D. G. Neary, and R. S. Mansell. 1992. *The effectiveness of buffer strips for ameliorating offsite transport of sediment, nutrients, and pesticides from silvicultural operations.* Technical Bulletin No. 63 1, National Council of the Paper Industry for Air and Stream Improvement Inc., Research Triangle Park, N.C.

Conner, W. H., and M. Brody. 1989. Rising water levels and the future of southeastern Louisiana swamp forests. *Estuaries* 12:3 18-323.

Conner, W. H., and M. Buford. 1998. Southern deepwater swamps. Pp. 261-287 in *Southern forested wetlands: Ecology and management,* edited by M. G. Messina and W. H. Conner. Boca Raton, Fla.: Lewis Publishers/CRC Press.

Conner, W. H., J. W. Day Jr., R. H. Baumann, and J. Randall. 1989. Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. *Wetlands Ecology and Management* 1:45–56.

Conner, W. H., K. W. McLeod, and E. Colodney. 2002. Restoration methods for deepwater swamps. Pp. *39-42* in *Proceedings of a Conference on Sustainability of Wetlands and Water Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Department of the Interior. 1988. *The impact of federal programs on wetlands.* Vol. 1. *The lower Mississippi alluvial floodplain and the prairie pothole region.* A Report to Congress by the Secretary of the Interior, Washington, D.C.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266:754–762.

Finger, T. R., and E. A. Stewart. 1987. Response of fishes to flooding regime in lowland hardwood wetlands. Pp. *86-92* in *Community and evolutionary ecology of North American stream fishes,* edited by W. J. Matthews and D. C. Heins. Norman: University of Oklahoma Press.

Gardiner, E. S., D. R. Russell, M. Oliver, and L. C. Dorris Jr. 2002. Bottomland hardwood afforestation: State of *the* art. Pp. *75-86* in *Proceedings of a Conference on Sustainability of Wetlands and Water Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Gore, J. A., and F. D. Shields Jr. 1995. Can large rivers be restored? *BioScience* 45:142–152.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience* 41:540–551.

Hamel, I? B., and E. R. Buckner. 1998. How far could a squirrel travel in the treetops? A prehistory of the southern forest. Pp. *309-315* in *Transactions of the 63rd North American wildlife and natural resources conference (Mar. 20-24, Orlando, Florida),* edited by K. G.Wadsworth. Wildlife Management Institute, Washington, D.C.

Hamel, I! B., T. Nuttle, C. A. Woodson, and F. Broerman. 2002. Forest restoration as ecological succession: Should we speed it up or slow it down? Pp. 98-108 in *Proceedings of a Conference on Sustainability of Wetlands and Water Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Harrington, C. A. 1999. Forests planted for ecosystem restoration or conservation. New *Forests* 17(1–3):175–190.

Hook, D. D. 1984. Waterlogging tolerance of lowland tree species of the South. *Southern Journal of Applied Forestry 8: 136-149.*

Hoover, J. J., and K. J. Killgore. 1998. Fish communities. Pp. *237-260* in *Southern forested wetlands: Ecology and management,* edited by M. G. Messina and W. H. Conner. Boca Raton, Fla.: Lewis Publishers/CRC Press.

Houston, A, E. 199 I. Beaver control and reforestation of drained beaver impoundments. Ph.D. diss., University of Tennessee, Knoxville.

Huang, W.-Y., K. Algozin, D. Ervin, and T. Hickenbotham. 1990. Using the Conservation Reserve Program to protect groundwater quality. *Journal of Soil and Water Conservation* 46:251–254.

Johnson, W. C. 1988. Estimating dispersibility of *Acer, Fraxinus,* and *Tilia* in fragmented landscapes from patterns of seedling establishment. *Landscape Ecology* 1:175–187.

Joslin, J. D., and S. H. Schoenhola. 1998. Measuring the environmental effects of converting cropland to short-rotation woody crops: A research approach. *Biomass and Bioenergy* 15:301–3 11.

Junk, W. J., I? B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pp. 1 IO-127 in *Proceedings of the international Large river symposium,* edited by D. I? Dodge. Canadian Special Publication Fisheries and Aquatic Sciences 106. Ottawa, Canada.

Kanowski, P. J. 1997. Afforestation and plantation forestry. In *Proceedings of the 11th World Forestry Congress (Oct. 13–22, 1997, Antalya, Turkey).* Accessed 11/27/02: coombs.anu.edu.au/Depts/RSPAS/RMAP/kanow.htm.

Killgore, K. J., and J. A. Baker. 1996. Patterns of larval fish abundance in a bottomland hardwood wetland. *Wetlands* 16(3):288–295.

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

Knowles, 0. H., and J. A. Parrotta. 1995. Amazonian forest restoration: An innovative system for native species selection based on phenological data and field performance indices. *Commonwealth Forestry Review* 74:230–243.

Lamb, D., and M. Tomlinson. 1994. Forest rehabilitation in the Asia-Pacific region: Past lessons and present uncertainties. *Journal Tropical Forest Science* 7:157–170.

Larsen, J. B. 1995. Ecological stability of forests and sustainable silviculture. *Forest Ecology and Management* 73:85–96.

Lockaby, B. G., and J. A. Stanturf. 2002. Potential effects of restoration on biogeochemical functions of bottomland hardwood ecosystems. Pp. 116-l *19* in *Proceedings of a Conference on Sustainability of Wetlands and Water Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Lockhart, B. R., A. W. Ezell, J. D. Hodges, and W. K. Clatterbuck. 1999. Development of mixed cherrybark oak-sweetgum plantations planted at different spacings in easr-central Mississippi after seventeen years. Pp. 103-106 in *Proceedings of the 10th biennial southern silvicultural research conference (Feb. 16–18, 1999, Shreveport, La.),* edited by J. D. Haywood. USDA Forest Service, General Technical Report SRS-30, Asheville, N.C.

Lowrance, R R, R L. Todd, J. Fail Jr., 0. Hendrickson, R Leonard, and L. Asmussen. 1984. Riparian forest as nutrient filters in agricultural watersheds. *BioScience* 34:374–377.

MacDonald, I? O., W. E. Frayer, and J. K. Clauser. 1979. *Documentation, chronology, and future projections of bottomland hardwood habitat losses in the Lower Mississippi Alluvial Plain.* Vols. 1 and 2. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Madsen, I?, Á. L. Aradóttir, E. Gardiner, P. Gemmel, K. L. Høie, M. Löf, J. Stanturf, I? Tigerstedt, H. Tullus, S. Valkonen, and V. Uri. 2002. Forest restoration in the Nordic countries. Pp. 120-125 in ***Proceedings of a Conference on Sustainability of Wetlands and Water Resources,*** edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Matthews, W. J. 1987. Physicochemical tolerance and selectivity of stream fishes as related to their geographic ranges and local distributions. Pp. 11 l-120 in ***Community and evolutionary ecology of North American stream*** fishes, edited by W. J. Matthews and D. C. Heins. Norman: University of Oklahoma Press.

McLeod, K. W., J. K. McCarron, and W. H. Conner. 1996. Effects of inundation and salinity on photosynthesis and water relations of four southeastern coastal plain forest species. ***Wetlands Ecology and Management*** 4(1):3 *l-42.*

Meadows, J. ***S.,*** and ***G.*** J. Nowacki. 1996. ***An old-growth definition for eastern riverfront forests.*** USDA Forest Service, General Technical Report SRS4, Asheville, N.C.

The Nature Conservancy. 1992. ***Restoration of the Mississippi River Alluvial Plain as a functional ecosystem.*** The Nature Conservancy, Baton Rouge, La.

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

Noss, R. F., E. T. Laroe III, and J. M. Scott. 1995. ***Endangered ecosystems of the United States: A preliminary assessment of loss and degradation.*** Biological Report 28, U.S. Department of the Interior, National Biological Service, Washington, D.C.

O'Connell, M. T. 2000. The direct exploitation of prey on an inundated floodplain by cherryfin shiners, ***Lythrurus roseipinnis,*** in a low order, blackwater stream. Ph.D. diss., University of Southern Mississippi, Hattiesburg.

Parrotta, J. A. 1992. The role of plantation forests in rehabilitating tropical ecosystems. ***Agriculture, Ecosystems, and Environment 4*** 1: 115-l 33.

Parrotta, J. A., J. W. Turnbull, and N. Jones. 1997. Catalyzing native forest regeneration on degraded tropical lands. ***Forest Ecology and Management 99:*** l-7.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime. ***Bioscience*** 47:769–784.

Putnam, J. A., G. M. Furnival, and J. S. McKnight. 1960. ***Management and inventory of southern hardwoods.*** Agriculture Handbook Number 181, USDA Forest Service, Washington, D.C.

Santiago Declaration. 1999. ***Statement on criteria and indicators for the conservation and swtainabk management of temperate and boreal forests.*** 2d ed. Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests ("Montreal Process"), Santiago, Chile. Accessed 1 1/18/02: www.fs.fed.us/global/pub/santiago.htm.

Savage, L., D. W. Pritchett, and C. E. DePoe. 1989. Reforestation of a cleared bottomland hardwood area in northeast Louisiana. ***Restoration and Management Notes*** 7:88.

Schlamadinger, B., and G. Marland. ***2000. Land use and global climate change—forests, land management, and the Kyoto Protocol.*** Pew Center on Global Climate Change, Arlington, Va.

Scholtens, L. J. R. 1998. Environmental, developmental and financial risks of tropical timber plantation investment funds. ***Natural Resources Forum*** 22(4):271–277.

Schweitzer, C. J., J. A. Stanturf, J. I? 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 River Alluvial Valley. Pp. 313-320 in *Proceedings of the 11th central hardwoodforest conference (Mar. 23–26, 1997, Columbia, M .), edited by S.* G. Pallardy, R. A. Cecich, H. G. Gartett, and P. S. Johnson. USDA Forest Service, 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:* I-10.

Sharitz, R. R. 1992. Bottomland hardwood wetland restoration in the Mississippi Drainage. Pp. 496–505 in *National Research Council (U.S.). Restoration of aquatic ecosystems: Science, technology, and public policy.* Report of the Committee on Restoration of Aquatic Ecosystems-Science, Technology, and Public Policy. Washington, D.C.: National Academy Press.

Sharitz, R. R., M. R. Vaitkkus, and A. E. Cook. 1993. Hurricane damage to an old-growth floodplain forest in the southeast. Pp. 203–210 in *Proceedings of the 7th biennial southern silvicultural research conference (Nov. 17–19, 1992, Mobile, Ala.),* edited by J. C. Brissette. USDA Forest Service, General Technical Report SO-93.

Shepard, J. I.?, S. J. Brady, N. D. Cost, and C. G. Storrs. 1998. Classification and inventory. Pp. 1-28 in *Southern forested wetlands: Ecology and management,* edited by M. G. Messina and W. H. Conner. Boca Raton, Fla.: CRC/Lewis Press.

Shields, F. D., and R. H. Smith. 1992. Effects of large woody debris removal on physical characteristics of a sand-bed river. *Aquatic Conservation: Marine and Freshwater Ecosystems* 2:145–163.

Smith, D. M. 1986. *Thepractice of silviculture.* 8th ed. New York: John Wiley and Sons.

Smock, L. A. 1999. Riverine floodplain forests of the southeastern United States. Pp. 137-165 in *Invertebrates in freshwater wetlands of North America: Ecology and* management, edited by D. I? Batzer, R. B. Rader, and S. A. Wissinger. New York: John Wiley and Sons.

Smock, L. A., G. M. Metzler, and J. E. Gladden. 1989. Role of debris dams in the structure and functioning of low-gradient headwater screams. *Ecology* 70:764–765.

Solberg, B. 1997. Forest biomass as carbon sink-economic value and forest management/policy implications. *Critical Reviews in Environmental Science and Technology* 27 (Special):S323–S333.

Stanturf, J. A. 2002. Forest restoration in a global context. Pp. 160–167 in *Proceedings of a Conference on Sustainability of Wetlands and* Water *Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

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(8):10–16.

Stanturf, J. A., and I? Madsen. 2002. Restoration concepts for temperate and boreal forests of North America and Western Europe. *Plant Biosystems 36* (2):143-158.

Stanturf, J. A., and C. J. Portwood. 1999. Economics of afforestation with eastern cottonwood (*Populus deltoides)* on agricultural land in the Lower Mississippi Alluvial Valley, Pp. 66-72 in *Proceedings of the 10th biennial southern silvicultural research conference (Feb. 16–18, 1999, Shreveport,* La.), edited by J. D. Haywood. USDA Forest Service, General Technical Report SRS-30.

Stanturf, J. A., and S. H. Schoenhola. 1998. Soils and landforms. Pp. 123-147 in *Southern forested wetlands: Ecology and management,* edited by M. G. Messina and W. H. Conner. Boca Raton, Fla.: CRC/Lewis Press.

Stanturf, J. A., S. H. Schoenhola, C. J. Schweitzer, and J. I? Shepard. 2001. Achieving restoration success: Myths in bottomland hardwood forests. *Restoration Ecology* Y(2): 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, USA. *Silva Fennica* 32:28 l-297.

Sterninke, H. S. 1976. Impact of changing land use on Delta hardwood forests. *Journal of Forestry* 74:25–27.

Taylor, C. A., M. L. Warren Jr., J. F. Fitzpatrick Jr., H. H. Hobbs III, R. F. Jaerinac, W. L. Pflieger, and H. W. Robison. 1996. Conservation status of the crayfishes of the United States and Canada. *Fisheries* 21(4):25–38.

Thornton, F. C., J. D. Joslin, B. R. Bock, A. Houston, T. H. Green, S. Schoenholtz, D. Pettry, and D. D. Tyler. 1998. Environmental effects of growing woody crops on agricultural land: First year effects on erosion, and water quality. *Biomass and Bioenergy* 15:57–69.

Twedt, D. J., and J. Portwood. 1997. Bottomland hardwood reforestation for Neotropical migratory birds: Are we missing the forest for the trees? *Wildlife Society Bulletin* 25:647–652.

Twedt, D. J., R. R. Wilson, J. L. Henne-Kerr, and R. B. Hamilton. 1999. Impact of bottomland hardwood forest management on avian bird densities. *Forest Ecology and Management* 123:261–274.

U.S. EPA (United States Environmental Protection Agency). 1999. *Integrated assessment of hypoxia in the northern Gulf of Mexico.* Draft for public comment. U.S. Environmental Protection Agency, Gulf of Mexico Program, Stennis Space Flight Center, Miss.

Walker, J. L., and W. D. Boyer. 1993. An ecological model and information needs assessment for longleaf pine ecosystem restoration. Pp. 138-147 in *Proceedings of the National Silviculture Workshop on Silviculture: From the cradle of forestry to ecosystem management (Nov. 1–4, 1993, Hendersonville,* N.C.), compiled by L. H. Foley. USDA Forest Service, General Technical Report SE-88.

Wallace, J. B., S. L. Eggert, J. L. Meyer, and J. B. Webster. 1997. Multiple trophic levels of a forest stream linked to terrestrial litter inputs. *Science* 277:102–104.

Warren, M. L., Jr., B. M. Burr, S. J. Walsh, H. L. Bart Jr., R. C. Cashner, D. A. Etnier, B. J. Freeman, B. R. Kuhajda, R. L. Mayden, H. W. Robison, S. T. Ross, and W. C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. *Fisheries* 25(10):7–29.

Warren, M. L., Jr., W. R. Haag, and S. R. Adams. 2002. Fish communities of lowland stream systems: Forest linkages to diversity and abundance. Pp. 168-182 in *Proceedings of a Conference on Sustainability of Wetlands and Water Resources,* edited by M. M. Holland, M. L. Warren Jr., and J. A. Stanturf. USDA Forest Service, General Technical Report SRS-50.

Weaver, K. M., D. K. Tabberer, L. U. Moore Jr., G. A. Chandler, J. C. Posey, and M. R. Pelton. 1990. Bottomland hardwood forest management for black bears in Louisiana.

Fish and Wildlife Agencies 44:342–350.

Wesley, D. E., C. J. Perkins, and A. D. Sullivan. 1981. Wildlife in cottonwood plantations. *Southern Journal of Applied Forestry* 5:37–42.

Whalley, D. N. 1988. Afforestation of salt-affected soils: An international problem. *International Plant Propagator? Society Combined Proceedings* 37:212–22 1.

Williams, J. D., M. L. Warren Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. *Fisheries* 18(9):6–22.