Lower Mississippi Alluvial Valley, USA Case Study

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Lower Mississippi Alluvial Valley	
Objectives	Initially, restoration by federal and state programs directly on publically-owned land was driven by the goal of enlarging and enhancing wildlife habitat. Also maintaining navigability of rivers in the LMAV and flood control by restoring riverine broadleaf forests.
Duration	15 years (1993 to 2008)
Target area to be restored	estimated 405,000 ha
Stakeholders and organisations	landowners, federal and state agencies, environmental NGOs, energy and other companies

1. Background

The Lower Mississippi Alluvial Valley (LMAV) covers more than 9.7 million hectares in parts of seven states extending from southern Illinois to the Gulf of Mexico (Figure 1). Historically, the LMAV was mostly riverine broadleaf forests (locally called bottomland hardwood forests). Alluvial floodplain forests exhibit high species richness and spatial diversity of vegetation communities (Kellison et al., 1998). More than 70 tree species are endemic to bottomland hardwood forests along with numerous vines, shrubs and herbaceous species (Putnam, Furnival, and McKnight, 1960). Deforestation, begun in the 1800s, and draining of wetland areas, intensified in the 1900s, has resulted in a loss of critical wildlife and fish habitat, decreased water quality, reduced floodwater retention, and increased sediment loads. Between 1950 and 1976, approximately one-third of the LMAV's bottomland forests were converted to agriculture (Stanturf et al., 2000). Land was cleared in the 1960s and 1970s primarily for soybean (*Glycine max* (L.) Merr.) production (Sternitzke, 1976) as a consequence of high commodity prices, development of short-growing season soybean varieties, and a prolonged dry period. By the 1980s less than 20 percent of the original forest was left. Nevertheless, much of the land deforested in this latest round of clearing remained at risk for late spring and early summer flooding.

Figure 1. The Lower Mississippi Alluvial Valley stretches from Illinois to the Gulf of Mexico.

Restoration of the bottomland hardwoods forests of the LMAV illustrates the complexity of restoration in a mixed-ownership landscape. Multiple federal, state, and private entities with a stake in restoring this landscape each have their own culture and agenda; at times the interests of the agencies may overlap but may be at odds with landowner interests.

2. Objectives

Restoration Programs on Public Land

Initially, restoration by federal and state programs directly on publically-owned land was driven by the goal of enlarging and enhancing wildlife habitat. The federal Fish and Wildlife Service (USFWS) in particular focused on their system of wildlife refuges to restore habitat for migratory waterfowl, the endangered Louisiana black bear, and Neotropical migratory songbirds. Some of the private land cleared for soybeans but subject to flooding in the growing season came into federal ownership by foreclosure (loan defaults by farmers) and was added to the refuge system. For example, staff of the Theodore Roosevelt National Wildlife Refuge Complex in Mississippi afforested 10,000 ha of former agricultural land, bringing the Complex's total acreage of bottomland forest to 27,000 ha (Gardiner et al., 2008). The USFWS also partnered with private landowners adjoining refuges to restore habitat, primarily for waterfowl.

Other federal agencies with different authorities than the USFWS are actively restoring bottomland hardwood forests. The mandate of the US Army Corps of Engineers (USACE) is to maintain navigability of rivers in the LMAV and also control flooding. Ongoing operations and maintenance activities (dredging, channel bank clearing, etc.) sometimes cause degradation of wetlands that requires mitigation through restoration or creation of wetlands elsewhere. One such mitigation area was afforestation of cropland and creation of the 3,400-ha Lake George Wildlife Management Area (WMA) in Yazoo County, Mississippi. This WMA is owned by the Vicksburg District of the USACE and is maintained by the Mississippi Department of Wildlife, Fisheries, and Parks. The USACE is also responsible for granting permits to private entities for mitigation banking on private land.

Restoration on Private Land

Bottomland hardwood forest restoration occurs on privately-owned land as well. The Conservation Reserve Program (CRP) and Wetland Reserve Program (WRP) are important national conservation tools designed to retire environmentally sensitive agricultural land from production. Nationally, the nearly USD 2 billion annual budget for the CRP is the largest public–private partnership for conservation and habitat protection. The WRP is smaller but plays an important role in preserving wetlands (Ferris and Siikamäki, 2009). Both the WRP and the CRP have provided federal funding for restoration on private land in the LMAV.

The federal Department of Agriculture (USDA) is responsible for CRP and WRP implementation; both programs are periodically re-authorized under the Farm Bill legislation. Program details have changed with each Farm Bill, and implementing rules vary by state. Swampbuster is a provision of the Food Security Act of 1985 (P.L. 99-198) that discourages the conversion of wetlands to cropland use. Producers converting a wetland area to cropland lose eligibility for several federal farm program benefits. Several types of wetlands and wetlands in specified situations are exempt, including conversions that began before the law went into effect. Swampbuster provisions have been extended in subsequent Farm Bills, with minor adjustments.

Wetlands Reserve Program

The WRP provides for several easement and contract options, with USDA paying for all or a portion of costs including administrative costs and legal fees; a lump-sum value of the easement; and restoration costs. The landowner retains ownership of the land and the ability to sell it; the right to control access; ownership of subsurface resources and water rights; and use for undeveloped recreational pursuits such as hunting (including the right to lease hunting access under the appropriate state game laws). The USDA payment to the landowner varies by the length of the easement or contract (see Box 1).

Box 1: Wetlands Reserve Program Contract Arrangements

- Permanent Easement: A conservation easement in perpetuity. USDA pays 100 percent of the easement value and up to 100 percent of the restoration costs.
- 30-Year Easement: An easement that expires after 30 years. USDA pays up to 75 percent of the easement value and up to 75 percent of the restoration costs.
- Restoration Cost-Share Agreement: An agreement to restore or enhance the wetland functions and values without placing an easement on the enrolled acres. USDA pays up to 75 percent of the restoration costs.
- 30-Year Contract: A 30-year contract option is only available on Native American lands. USDA pays up to 75 percent of the restoration costs.

Conservation Reserve Program

The CRP provides incentives to producers who utilize conservation methods on environmentally-sensitive lands. Landowners are monetarily compensated for establishing long-lived vegetative species, such as approved grass or tree covers to control soil erosion, improve water quality, and enhance wildlife habitat. The CRP contracts are of shorter duration than WRP; eligible land can be enrolled in CRP with contracts of up to 10 to 15 years in duration and either re-enrolled or put back into production. CRP has several authorities and practices that provide for bottomland hardwood forest restoration including some approaches that until very recently (2012), were not approved for WRP, such as a nurse-crop system that uses a fast growing native species (Eastern cottonwood, *Populus deltoides*) interplanted with slower-growing native hardwoods such as *Quercus* spp. (Stanturf et al., 2000; Stanturf et al., 2009; Gardiner, Stanturf, and Schweitzer, 2004). Authorities approving the nurse-crop system include CP 31 (Bottomland Timber Establishment on Wetlands), CP 23 (Wetland Restoration Inside the 100 Year Floodplain) and CP 38 (SAFE: State Acres for Wildlife Enhancement).

Wetlands Reserve Enhancement Program

Additional flexibility for innovation is provided by the Wetlands Reserve Enhancement Program (WREP), a component of the WRP. WREP is a voluntary conservation program that works through partnership agreements with states, nongovernmental organizations, and Native American tribes. WREP provides the ability to cost-share restoration or enhancement components beyond those required by the Natural Resources Conservation Service (NRCS), the implementing agency for WRP. With WREP, the NRCS enters into agreements with eligible partners to leverage resources to carry out high-priority wetland protection and improve wildlife habitat (see Box 2).

Box 2: The Wetlands Reserve Enhancement Program
Using WREP, the Mississippi River Trust and Lower Mississippi River Conservation Committee offer monetary incentives to landowners in the land between the flood protection levees, an area known as the "batture." This Lower Mississippi River Batture Reforestation (sic) program began in May 2012 and conservation easements on more than 4,000 ha have been secured to afforest cleared land. Matching funds are provided by the Walton Family Foundation (endowed by the Walmart founder) and the U.S. Endowment for Forestry and Communities, a not-for-profit corporation established in 2006 with a USD 200 million endowment in accordance with the terms of the Softwood Lumber Agreement between the US and Canada.

3. Achievements and Outcomes

Although data on restoration are scant and scattered, best estimates are that over the past three decades, forest restoration in the LMAV portions of Louisiana, Mississippi, and Arkansas has increased dramatically. Between 1993 and 2008, an estimated 405,000 ha were restored and almost 162,000 ha of existing forests protected through easements (Table 1).

Table 1. Estimated area of bottomland hardwood forest restoration in the LMAV

Program or Agency	State	Hectares	
WRP	LA	72,844	
	MS	55,847	
CRP	LA	80,938	
	MS	132,738	
WREP		4,047	
CarbonFund	LA	757	
Utilitree		1,376	4 refuges
PowerTree		15,783	
Illinova		40,469	5 states
		404,799	
Easements	LA	89,032	
		68,797	DU
		157,829	

4. Contributions to Climate Change Mitigation and Adaptation

Carbon Sequestration

Payments for ecosystem services such as carbon sequestration have funded restoration in the LMAV. The first programs were developed by energy companies partnering with the USFWS. Typically, energy companies purchased and restored land based on USFWS priority conservation needs, donated the restored lands to the Refuge System, provided limited operational funds, and retained the right to sell or market their carbon credits. Pioneered in the LMAV, this program has spread nationwide. Diverse partnerships have developed to include the Trust for Public Land, The Conservation Fund, The Nature Conservancy, Illinova, Dynergy, Entergy, American Electric Power, DTE Energy, Texaco, Ducks Unlimited, Volkswagen, Gaiam, the CarbonFund and utility consortiums such as PowerTree and Utilitree (see Box 3).

Box 3: PowerTree Carbon Company project developers, projects, locations and sizes are:

- The Conservation Fund: Spanish Lake Project, near Alexandria and Natchitoches, Louisiana., 367 ha
- Old South Woodlands LLC: Walsh Lake Project, near Larto, Louisiana, 202 ha
- Central Arkansas Resources Conservation and Development Council: White River Project, near Newport, Arkansas, 445 ha
- The Nature Conservancy: Bayou Pierre Project, near Natchitoches, Louisiana, 202 ha
- The Conservation Fund: Bayou Pierre II Project, near Natchitoches, Louisiana, 80 ha
- Ducks Unlimited: Bayou Bartholomew Project, near Mitchellville, Arkansas, 161 ha
- The Carbon Fund: Southfresh Farms Project, near Belzoni, Mississippi, 80 ha

PowerTree Carbon Company is a multi-million dollar company established to undertake seven bottomland hardwood restoration projects in Louisiana, Mississippi and Arkansas on 1,600 ha. Together the member companies have invested USD 3 million to plant 1.2 million trees in bottomland, hardwood restoration projects.

Illinova Corporation, an energy company headquartered in Illinois, has pledged USD 13.7 million to the National Fish and Wildlife Foundation to restore more than 40,000 ha in the Lower Mississippi River Valley. The National Fish and Wildlife Foundation will work with Environmental Synergy, Inc. to reforest 8,000 ha per year for 5 years on 13 USFWS refuges in five states, including Arkansas, Illinois, Louisiana, Mississippi, and Tennessee. Utilitree Carbon Company, a consortium of more than 40 utility companies, is sponsoring more than 950 ha of restoration on marginal farmland on four national wildlife refuges in the LMAV as part of its Global Climate Challenge Program.

Carbon payments are also driving restoration on private land. GreenTrees is a program that aims to reforest 404,000 ha in the Lower Mississippi Alluvial Valley. Funded by Duke Energy and Norfolk Southern Railways, the program is expected to generate high-quality, verifiable carbon offsets that can be used to reduce the overall cost of compliance with potential federal climate change legislation. Under the program, GreenTrees enters into 70-year carbon offset lease agreements with willing landowners. These long-term agreements minimize the risk of future deforestation and encourage the long-term storage of carbon dioxide in the trees, roots and soil on the land.

Landowners retain land use and can simultaneously benefit from multiple revenue streams generated by their property, including: recreational revenue; conservation tax benefits; potential access to federal funds, such as the CRP. The landowner also has the right to harvest and sell select amounts of timber within the guidelines of the program. GreenTrees uses a modification of the nurse crop system. Their design interplants 746 mixed species hardwood seedlings and 746 cuttings on a 1.85 m by 3.7 m spacing for a total planting of 1,492 trees per ha. This 746-746 forest design has been approved by USDA as an acceptable conservation cover to be used in the CRP. Qualified landowners can simultaneously enroll in CRP and GreenTrees. GreenTrees offers USD 865 per ha during the planting period, with added short- and long-term income coming to the producer in addition to, and independent of, the 15 years of annual CRP payments. The interplanting technique has been applied by GreenTrees on 9,000 ha to date.

Forest Landscape Restoration

Several efforts have attempted to coordinate efforts and identify optimal allocation of restoration effort. The Lower Mississippi Valley Joint Venture (LMVJV) is a self-directed, non-regulatory private, state, and federal conservation partnership that exists for the purpose of sustaining bird populations and their habitats within the LMAV and West Gulf Coastal Plain regions through implementing relevant national and international bird conservation plans. LMVJV has developed Conservation Delivery Networks (CDNs) that are forums whereby members of the Joint Venture and other appropriate conservation organizations coordinate on-the-ground delivery of their otherwise independent efforts. The scope of coordination is intended to include not only individual projects, but also the larger programs of partners attempting to deal with emerging challenges such as urban sprawl, habitat loss and degradation, altered hydrology. Recently, the potential long-term effects of global climate change have begun to be addressed. CDNs provide a functional link for translating biological planning and conservation design tools (science at landscape scales) to action on the ground.

The Lower Mississippi River Resource Assessment is a study of information needed for river-related management; the needs of natural habitats and the species they support; and the need for more river-related recreation and public access. The study is meant to inform Congress and promote additional funding to address identified needs. The Assessment is funded by the federal Environmental Protection Agency and other federal agencies, State agencies, and Tribes within the Mississippi and Atchafalaya River Basin. Strategies for nutrient reduction are under development, including identifying opportunities to restore floodplain wetlands (including restoration of river inflows) along and adjacent to the Mississippi River.

Restoration Methods

The restoration strategy developed by the USFWS and adopted in the early days of the WRP (Haynes, 2004) involved planting as many hectares as possible with the limited funds available, concentrating on establishing the heavy-seeded species such as *Quercus* spp. that were difficult to establish and were important to wildlife, and relying on native recolonization to add diversity and increase stocking. Examination of the earliest plantings (Allen et al., 2001; Allen, 1997) indicated that mortality often was less than anticipated and the resulting stands, often of a single species, gave other natives little opportunity to recolonize. To facilitate colonizer establishment and enhance biodiversity, Allen (1990) recommended direct seeding because of the gaps left by mortality. Direct-seeding and native recolonization became critical elements of the WRP approach to restoration as adopted by the implementing agency, the NRCS. Planting density in the WRP was lowered, however, to produce a more widely spaced oak stand in order to improve opportunities for other woody species to establish. Problems arose early on as small restoration patches within a large matrix of active agricultural land had few sources for seeds of forest trees within effective dispersal distance. Absent substantial native recolonization, the resulting stands were likely to be understocked and of low quality for timber management (Stanturf et al., 2001).

Other factors contributing to many early failures of the WRP included inattention to site adaptations of species and the complex but subtle relationship of topography to growing season inundation that resulted in off-site plantings; and the failures of direct seeding and planting that were likely due to contractor crews experienced with planting conifers but not broadleaves. Other methods have been developed and adopted (Gardiner and Oliver, 2005; Stanturf, Schweitzer, and Gardiner, 1998; Lockhart et al., 2008) and experience gained, leading to a successful restoration program. For example, Ducks Unlimited (DU) is a conservation non-profit organization with one of the largest private conservation, protection, and restoration efforts, involving tens of thousands of hectares in the Mississippi Alluvial Valley (Box 4). Working with agencies and landowners, DU has implemented the WRP on more than 97,000 ha of afforestation and hydrology restoration in the LMAV, and through conservation easements donated to Wetlands America Trust; private landowners in the LMAV have permanently protected the habitat values of more than 69,000 ha.

Box 4: Water quality enhancement decision support system:
With support from the Restoring the Delta Program of the USDA Forest Service, Ducks Unlimited developed a web-deployed water quality enhancement decision support system built upon a GIS and remote sensing platform. Project STREAM (System for Targeting Restoration and Enhancing Aquatic Monitoring) contains watershed planning datasets that will help regional water quality professionals analyze watersheds and determine beneficial sites for water quality enhancement work. Coupled with a Wetland Restoration Suitability Index, these decision support tools provide a resource for conservation delivery agents and planners seeking to maximize the ecological benefits of restoration.

Mitigation/Adaptation Assessment

The restoration program in the LMAV began before climate change reached prominence as a conservation issue. Nevertheless, substantial potential for mitigation and adaptation exists within current restoration activities in the LMAV. The greatest mitigation potential has been realized by the carbon sequestered in aboveground biomass resulting from the increase in forest area through afforestation of retired agricultural land approximately 405,000 ha to date. Some increase in biomass/unit area has been realized in this afforestation effort by increasing productivity, mostly by better weed control at planting that allows quicker capture of the site and greater production of biomass than occurs on sites without adequate weed control (Stanturf et al., 2004). Because this has not been adopted on WRP plantings due to administrative hurdles, the potential has not been fully realized.

Carbon sequestration occurs belowground in the soil as well as in aboveground biomass. Soil carbon has increased by planting longer-lived and more deeply-rooted species (trees instead of annual crops), although it takes longer to realize a significant gain (Stanturf et al., 2001; Stanturf et al., 2009). Another mitigation objective, reduction of greenhouse gas (GHG) emissions, can be achieved by use of bioenergy and development of bioenergy plantations. This is an active area of research in the LMAV but to date there are no operational bioenergy plantations. Nevertheless, the long history in the LMAV of research and management on short-rotation *Populus deltoides* plantations, and the initiation of research and breeding of native *Salix* spp., provides a sound foundation for developing sustainable supply.

Maintaining forest area by reducing deforestation drivers is a fundamental approach for adapting to climate change. Policy reforms begun in the 1970s culminated in the inclusion of "Swampbuster" provisions in the Farm that reduced or eliminated commodity support and other incentive payments to farmers that converted wetlands to agriculture. This provision has been maintained in subsequent re-authorizations of the Farm Bill and effectively halted conversions of forest to agriculture in the LMAV. Clearing still occurs, however, for infrastructure and urban development; many times, permitting processes require mitigation of wetland taking. Other means have been used to maintain forest cover, in particular conservation easements whereby a landowner receives some compensation for legally restricting development of forest to non-forest use. Perhaps the most sustainable deterrent to deforestation is increasing the economic value of forest land to the owner through increases in productivity. Some limited success has been achieved by improving silviculture of existing forests. Regeneration methods adapted from other regions generally are inapplicable to the LMAV because the bottomland hardwood forests are species rich and subject to frequent disturbances, characteristics that favor competition from non-desirable species that impede successful regeneration.

Sustainable management practices and harvesting methods maintain carbon stocks by reducing degradation of existing forests. As noted, improving regeneration following harvest is critical and begins many years before final harvest by management that establishes and promotes development of advance regeneration, particularly of *Quercus* spp. Other forest functions have been maintained by management that promotes biodiversity. These practices include afforestation with a variety of native species and development of mixed species plantings. In native forests, recovery of endangered species including the Louisiana black bear (*Ursus* *americanus luteolus*) and the endangered shrub pondberry (*Lindera melissifolia*) has been advanced through research and management efforts. Habitat management for other species of concern, specifically Neotropical migratory songbirds, has benefited from public-private partnerships (e.g., the LMJV) as well as research and management efforts.

Watershed functions are critical in the LMAV at multiple scales. As noted in the introduction to this case study, land management practices throughout the basin impact on the Gulf of Mexico Anoxic Zone, and river regulation has taken a toll on coastal wetlands including cypress swamp forests. Some localized improvement of hydrology has been accomplished by restoring microsites on land-leveled sites but overall restoration of natural floodplain hydrology is limited by development. Water quality could be improved by planting stream buffers but farmers are reluctant to adopt trees for buffers because of concerns for shading of their agricultural crops. The USACE and local water and levee boards responsible for flood control are concerned over potential obstruction of waterways by downed woody material, if buffer zones are unmanaged forest strips.

Managing for resistance by reducing vulnerability to stressors has only been possible in the instance of integrated pest management of *Populus* plantations and by securing advance regeneration of *Quercus* spp. in native forests. Managing for resilience has inadvertently occurred by expanding the population of species within the native range that are better adapted to drier conditions by the emphasis on planting *Quercus* spp. in afforestation. Beyond these two examples, little attention has been paid to adaptation to climate change.

5. Lessons Learned

The experience in the LMAV can be extrapolated to other programs for restoration of large areas and three lessons stand out: 1) the difficulty of extrapolating from small-scale research studies and controlled pilot projects to operational restoration, 2) differing objectives for restoration in a public–private ownership context, and 3) the value of focusing on restoring functional forested ecosystems.

Operational restoration—The problems that emerged when restoration efforts in the LMAV moved from small experimental plots to large-scale afforestation and from controlled planting on public land to operational planting on private land were typical of the issues that surface when scaling up from research to practice, from small-scale plantings to landscape-level efforts. Early experience with the WRP in the Delta Region of the state of Mississippi further underscored the criticality of proper prescriptions (site-adapted species) and nearby seed sources: only those restoration sites adjacent to natural stands achieved successful stocking levels because of problems with the restoration prescriptions (Stanturf et al., 2001; Stanturf et al., 2004).

Variable objectives over time in mixed ownership landscapes—Restoration practices attractive to landowners may not be acceptable to agency personnel or appropriate to public land. The interplanting technique popular with landowners has been resisted by the agencies responsible for the WRP and their objections were based on programmatic difficulty with the intensive measures required to establish cottonwood and the potential to harvest a commercial timber crop.

The treatments needed to establish the cottonwood, herbicides and disking (see image below), were said to reduce herbaceous diversity and thus wildlife value. The need to continue establishment treatments (disking but also planting the oak) beyond the first year presented procedural problems with the way in which payments to the landowner were structured. Nevertheless, interested landowners have instituted the interplanting scheme under the CRP program and 13,000 ha were enrolled for this treatment in the Continuous Sign-Up CRP program from 2003 to 2005. Uptake of the basic design by GreenTrees with adjustments for carbon sequestration has expanded use; the eventual goal of GreenTrees and its partners is for over 400,000 ha.

Focus on restoring functions—In restoring large areas of former agricultural land, managers can intervene to restore only a few species due to financial and other constraints so that complete restoration will require effective natural dispersal and long time periods. Ecological restoration guidelines measure success in terms of attaining the structure and composition of reference stands (SERI, 2004). Although there are numerous drawbacks to using reference stands to measure success (Clewell and Lea, 1990), they are useful in defining goals and realistic expectations (Anderson and Dugger, 1998; Burton, 2014). Using reference sites to define restoration success in highly modified landscapes faces other problems: in areas of drainage and levee construction such as the LMAV, regional hydrology has changed substantially within the lifetime of mature stands and the conditions under which reference stands established may be quite different from current conditions. Because much of the extensive floodplain of the Mississippi River has been isolated from most flood events of the river, sites are now ‘‘drier’’ and oaks have been planted in greater proportion than they may have been prior to European settlement (Ouchley et al., 2000), which may in fact be more adaptive to the future climate of the region.

Natural regeneration of oak is problematic (Oliver, Burkhardt, and Skojac, 2005), supporting the emphasis of restoration programs on establishing oak and other heavy-seeded species as the initial intervention. Experience suggests that complete restoration of species-rich forests with complex structures will require multiple interventions over time (Ashton et al., 2001; Kelty, 2006), but substantial functionality can be obtained in a short time using innovative techniques such as interplanting, especially if interventions are sequenced to take advantage of native recolonization and stand development processes. The early success of the interplanting technique in rapidly developing forested conditions and vertical structure demonstrated that environmental benefits can be obtained quickly by more intensive efforts (Stanturf et al., 2001). Native recolonization can be utilized to augment active interventions if limitations to dispersal distance are clearly recognized. The necessity of trading off costs with time needed to achieve desirable levels of environmental benefits underscores the importance of clearly defining at the outset restoration objectives and measures of success.

In place	❋
Partly In place	★
Not in place	✕

Table 2. Summary of Forest Landscape Restoration Success –LMAV Case Study

Theme	Feature	Key Success Factor	Response
Motivate	Benefits	Restoration generates economic benefits	❋
		Restoration generates social benefits	❋
		Restoration generates environmental benefits	❋
	Awareness	Benefits of restoration are publicly communicated	★
		Opportunities for restoration are identified	★
	Crisis events	Crisis events are leveraged	❋
	Legal requirements	Law requiring restoration exists	✕
		Law requiring restoration is broadly understood and enforced	★
Enable	Ecological conditions	Soil, water, climate, and fire conditions are suitable for restoration	❋
		Plants and animals that can impede restoration are absent	★
		Native seeds, seedlings, or source populations are readily available	❋
	Market conditions	Competing demands (e.g., food, fuel) for degraded forestlands are declining	❋
		Value chains for products from restored forest exists	★
	Policy conditions	Land and natural resource tenure is secure	❋
		Policies affecting restoration are aligned and streamlined	★
		Restrictions on clearing remaining natural forests exist	★
		Forest clearing restrictions are enforced	❋
	Social conditions	Local people are empowered to make decisions about restoration	❋
		Local people are able to benefit from restoration	❋
	Institutional conditions	Roles and responsibilities for restoration is clearly defined	★
		Effective institutional coordination is in place	★
Implement	Leadership	National and/or local restoration champions exist	★
		Sustained political commitment exists	❋
	Knowledge	Restoration "know-how" relevant to candidate landscape exists	❋
		Restoration "know-how" transferred via peers or extension services	★
	Technical design	Restoration design is technically grounded and climate resilient	★
	Finance and incentives	"Positive" incentives and funds for restoration outweigh "negative" incentives for *status quo*	❋
		Incentives and funds are readily accessible	★
	Feedback	Effective performance monitoring and evaluation system is in place	✕
		Early wins are communicated	❋

In place	❋
Partly In place	★
Not in place	×

Table 3. Summary of Mitigation and Adaptation Potential–LMAV Case Study

Mitigation/ Adaptation/ Transformation	Objective	Mechanism	Restoration Activity	Implementation Level
Mitigation	**Sequester carbon**	**Increase forest area**	**Afforestation**	❋
		Increase biomass/unit area	**Increase productivity**	★
			Longer –lived species	❋
		Increase soil carbon	**Increase rooting depth**	❋
	Reduce emissions	**Bioenergy**	**Bioenergy plantations**	★
Adaptation	**Maintain forest area**	**Reduce deforestation drivers**	**Policy reform--“Swampbuster” regulations**	❋
			Conservation easements	❋
			Improve silviculture	★
	Maintain carbon stocks	**Reduce degradation**	**Sustainable forest management (improve regeneration)**	★
	Maintain other forest functions	**Improve biodiversity**	**Afforest with mixed species**	★
			Recover endangered species (Louisiana black bear, pondberry)	★
			Manage for species of concern (Neotropical migratory songbirds)	★
		Improve hydrology	**Restore microsites**	×
			Plant stream buffers	×
	Manage for resistance	**Reduce vulnerability to stressors**	**Integrated pest management of *Populus deltoides* only**	★
		Overcome regeneration barriers	**Secure advance *Quercus* regeneration**	★
		Reduce vulnerability by breeding, introduce new provenances, genetic modification		×
	Manage for resilience	**Expand population (within range)**	**Emphasize *Quercus* spp. in afforestation**	★
		Expand range		×
		Create refugia		×
Transformation	**Novel ecosystems**	**Manage spontaneous ecosystems**	**Management of mixed plantings**	×
		Create ecosystems	**Translocate species**	×
			Replace species within assemblages with desired	×

		functional traits	
		Introduce exotics (non-native species) with desired functional traits	×

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