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Original article

# Development of restoration trajectory metrics in reforested bottomland hardwood forests applying a rapid assessment approach

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ABSTRACT

Large scale wetland restoration and reforestation efforts continue to expand throughout the Lower Mississippi Valley. Monitoring of restoration performance and the development of restoration trajectories pose challenges to resource managers and remain problematic due to (1) temporal patterns in forest succession, (2) budget constraints and short project monitoring timeframes, (3) disparity in the extent of pre-restoration hydrologic and landscape manipulations, and (4) lack of coherent restoration performance standards. The current work establishes a framework for identifying restoration trajectory metrics within project-relevant timescales. The study examined 17 variables commonly applied in rapid assessments. Four variables yielded positive restoration trajectories within a few years to 20 years. These include shrub-sapling density, ground vegetation cover, and development of organic and A soil horizons. Remaining variables including flood frequency and tree density provide limited useful information within critical early years following reforestation due to the time required for measurable changes to occur. As a result, assessment components are classified into three categories of rapid response, response, and stable variables. Restoring entities should maximize stable variables (e.g., afforestation species composition) during project implementation through site selection and planting techniques; while development of restoration milestones should focus on rapid response variables. Data collected at mature bottomland hardwood control sites displays the non-linearity of trajectory curves over decadal time scales.

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## 1. Introduction

A variety of factors including settlement expansion, agriculture and forestry, and flood control decreased wetland acreages within the Lower Mississippi Valley (LMV) by 74% by 1982; with only 2.8 of an original 10 million ha remaining today (Gardiner and Oliver, 2005; The Nature Conservancy, 1992; King et al., 2006). LMV wetland loss rates exceed all other portions of the United States, creating an area of concern in terms of both wetland acreage and wetland functional losses (Hefner and Brown, 1995). During the 1970s and 1980s public and private organizations recognized the negative impacts of wetland functional degradation and began promoting wetland restoration designed to repair damaged and degraded ecosystems within the region (U.S. Congress., 1985; Haynes et al., 1995; Hobbs and Cramer, 2008). In response, an estimated 275,000 ha of bottomland hardwood forest LMV has undergone reforestation, including over 20,000 acres under the jurisdiction of the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1989; Allen et al., 2000; King et al., 2006; King and Keeland, 1999). Recently, the science and practice of ecological restoration has evolved to focus on maximizing ecological functionality within current biotic and abiotic constraints (Harris et al., 2006; Jackson and Hobbs, 2009).

Despite increases in wetland acreage resulting from large-scale restoration projects, no consensus exists regarding performance standards or early successional trajectory curves in forested systems (Thom, 1997; Ruiz-Jaen and Aide, 2005; Hughes et al., 2005). Recent work suggests measures of performance focus on vegetation composition, ecosystem processes, species diversity, and structural benchmarks (Gardiner et al., 2004; Wilkins et al., 2003; Hamel, 2003; Allen, 1997). However, calibration of appropriate methods for determining restoration performance continues to lack clarity, specifically within the first few years following restoration (Steyer et al., 2003).

The time frames associated with forested wetland restoration complicate the establishment of performance standards (Hobbs and Harris, 2001; Kusler, 1986). Bottomland hardwood ecosystems require multiple decades to reach maturity, while regulatory agencies typically require less than a decade (commonly <5 years) of permit applicant sponsored post-project monitoring to determine

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**Table 1**
Summary of site characteristics: location, area reforested, number of independent forests sampled, age, and condition.

| County, State | Area replanted (ha) | Forests sampled | Age (years) | Condition |
|---|---|---|---|---|
| Bolivar, MS | 344 | 5 | 1 | Restored |
| Ouachita, LA | 1212 | 5 | 1 | Restored |
| Bolivar, MS | 1011 | 5 | 6–7 | Restored |
| Quitman, MS | 217 | 5 | 6–7 | Restored |
| Washington, MS | 140 | 5 | 6–7 | Restored |
| Washington, MS | 210 | 5 | 11–12 | Restored |
| Washington, MS | 186 | 5 | 11–12 | Restored |
| Yazoo, MS | 3499 | 10 | 20 | Restored |
| Yazoo, MS | – | 5 | >80 | Control |
| Sharkey, MS | – | 21 | >80 | Control |
| Total | 6819 | 71 | | |

restoration performance (Clewell and Lea, 1990; Landin and Webb, 1986). The temporal variability associated with ecosystem restoration remains problematic as few studies establish a restoration chronosequence exhibiting restored forest dynamics and functionality over time (Spencer et al., 2001).

In addition to the problems posed by forest successional changes, restoration trajectory is also influenced by the extent of site manipulation associated with restoring activities. For example many sites undergo plantings of ecologically desirable species (Stanturf and Gardiner, 2000; Humphrey et al., 2004), while other areas are subject to natural regeneration following clear-cutting or abandonment of previously farmed fields (Spencer et al., 2001; Battaglia et al., 2002). The amount of on-site preparation and changes to site hydrology and topography influence restoration outcomes, however the lack of an equal starting point for restoration complicates establishing performance standards. Often, responsible parties and agency staff are limited by budgetary and time constraints for post-restoration monitoring, compliance activities, and remediation of low quality restoration efforts.

The Hydrogeomorphic (HGM) Approach and other rapid assessment techniques examine wetland components to assess ecosystem function or condition (Brinson, 1993; Brinson et al., 1994; Stein et al., 2009). HGM has been widely applied because it specifically focuses on requirements of the Clean Water Act and has been utilized to monitor many wetland ecosystem types (Brinson and Rheinhardt, 1996; Klimas et al., 2004; Humphrey et al., 2004). HGM collects data on a number of structural ecosystem components and applies multimetric equations to develop an index of wetland function or condition; providing a practical basis for evaluating wetland areas.

Kentula et al. (1992) and Zedler (1996) identified the need for establishment of performance standards or criteria for ecological restoration and mitigation projects. Further, Smith and Klimas (2002) and Klimas et al. (2004) examined expected recovery patterns within selected wetland assessment variables. The current work builds upon the available literature by (1) identifying rapid assessment variables that respond quickly following restoration, (2) developing statistically significant early stage restoration performance standards for reforested wetlands, and (3) providing examples of potential applications for restoration trajectories.

## 2. Methods

### 2.1. Study area

Study area selection was based on criteria including (1) restoration project implemented within project relevant timescales (<20 years), (2) construction of a restoration chronosequence, (3) previous land use of 100% agricultural with no hydrologic restoration occurring onsite, and (4) located proximal to the region addressed by the assessment method developed for use in the study area. In order to minimize potentially confounding effects due to topographic location and hydrology, all selected study areas classified as riverine backwater wetlands as defined in Smith and Klimas (2002). Forty-five reforested sites ranging from 1 to 20 years post planting were examined during the study. The study area included sample plots located within the Yazoo Basin in Mississippi with one site located nearby in Louisiana (Table 1; Fig. 1).

Study area age was determined by the dates of reforestation activities and historical documentation. Restoration activities utilized seedling planting and did not include hydrologic modification such as alterations to existing water control structures (e.g., ditches or levees). Planted species included a mixture of water oak (*Quercus nigra*), willow oak (*Quercus phellos*), Nuttall oak (*Quercus texana*), Shumard oak (*Quercus shumardii*), green ash (*Fraxinus pennsylvanica*), pecan (*Carya illinoensis*), and bald cypress (*Taxodium distichum*).

Twenty-six mature control sampling plots were also examined within the Delta National Forest. Control sites exhibited second growth forests >80 years old and represent the least disturbed forested wetlands in the region. Sample areas receive hydrologic inputs from precipitation and backwater flooding and occur within meander belts 2 and 3 of the Mississippi river floodplain (Saucier, 1994). Soils throughout the study area were characterized by Sharkey, Dowling, Perry, and Alligator poorly drained clay soils with small inclusions of somewhat poorly drained Commerce silty clay loam. All observed soil series phases were between 0 and 2 percent slope (Soil Survey Staff, 2011).

### 2.2. Selection of variables and data collection

The selection of variables was based upon the assessment protocols outlined in Smith and Klimas (2002) who developed an HGM guidebook specifically calibrated within the study area. The potential application of HGM variables as measures of restoration trajectory provides several advantages including (1) data collection protocols are rapid (Berkowitz et al., 2010) and (2) utilize sampling measurements and protocols that resource professionals are familiar with (i.e., determination of tree diameter at breast height; Mack, 2007; Stander and Ehrenfeld, 2009). Further, the protocols provided in Smith and Klimas (2002) are currently applied as part of ongoing monitoring efforts, providing an available source of data with the potential to produce science-based, applicable tools for developing restoration trajectories and performance standards.

Smith and Klimas (2002) identify seventeen variables commonly applied in wetland assessments. Variables included off-site and on-site measurements. Off-site variables evaluated flood regime, restoration site configuration, and the characteristics of adjacent properties. On-site variables included examination of soil characteristics, vegetative composition and vigor, and the degree of site disturbance (Table 2). Smith and Klimas (2002) provide detailed