Water Quality Implications of Forest & Wetland Restoration in the Lower Mississippi Valley Joint Venture Geography

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Introduction

Restoring wetlands and riparian forests on crop fields can result in a variety of ecosystem services including water quality improvement, erosion and flood control, carbon sequestration, soil formation, habitat, biodiversity, and recreation. In the Mississippi Alluvial Valley (MAV), improved water quality is a particularly important wetland restoration outcome. The MAV is one of the most productive agricultural regions in the United States, with extensive row-cropping of corn, soybeans, cotton, and rice. Waters in the region drain into the northern Gulf of Mexico, contributing an estimated 11% of the nitrogen and 23% of the phosphorus total load the Gulf each year (Keerthi & Johnson, 2019). Nutrient loads to the Gulf result in the annual formation of one of the largest bottom-water hypoxic zones in the western Atlantic Ocean, the “dead zone”. Under optimum conditions, floodplain wetlands in the region can act as nutrient sinks and transformers when rivers overflow their banks into riparian areas, reducing nitrate reaching the Gulf of Mexico (Hurst et al., 2016).

Before European settlement, this region was the largest and most productive forested wetland ecosystem in North America. In the mid-nineteenth century, greater than 75% of riparian forests were cleared to control flooding along the Mississippi River and allow for agricultural activities to occur within the alluvial plain (Faulkner et al., 2011). The conversion and loss of wetlands and floodplain forests in the region reduces the capacity of the ecosystem to mitigate nutrient loading (Keerthi & Johnson, 2019a). The need for restoration was recognized in the North American Waterfowl Management Plan and the North American Bird Conservation Initiative and catalyzed by the passage of the 1990 Food, Agriculture, Conservation and Trade Act (Farm Bill) and the creation of the Wetlands Reserve Program (WRP; Wetlands Reserve Easements [WRE] beginning in 2019). The Wetlands Reserve is administered by the United States Department of Agriculture (USDA) that provides eligible landowners with financial incentives to voluntarily restore wetlands and retire marginal farmlands from agricultural production. Over 25 years, more than 750,000 acres of habitat has been restored and protected in Mississippi, Arkansas, and Louisiana through Wetland Reserve easements. In addition, significant restoration has stemmed from regulation-driven offsets for wetland impacts resulting from Civil Works occurring within the highly hydrologically modified watershed. Over 29,000 acres (ac) of bottomland hardwood forest previously converted to agriculture have been reclaimed by the US Army Corps of Engineers (USACE) as a result of unavoidable impacts associated with executing the Civil Works mission (Berkowitz et al., 2018).

The purpose of this report is to enhance Lower Mississippi Valley Joint Venture (LMVJV) partners’ ability to communicate the water quality benefits of converting row crop agricultural ground to emergent and forested wetland habitat, particularly in the MAV. While the benefits of restoration appear inherent and are often assumed, a better understanding of how water quality improvements result from restoration in the region is critical for optimizing outcomes and informing decision-making. This report serves as a collection of existing data to better understand how taking agricultural land out of production and restoring the landscape to a more natural state (e.g. emergent wetlands, riparian forest, and shrub-scrub) affects downstream water quality within the LMVJV region. Studies involving impacts of Wetlands Reserve, Conservation Reserve Program (CRP), and other Farm Bill programs are of special interest.

Methodology

A narrative literature review was conducted using published literature from scientific journals, agency reporting, and theses/dissertations. The goal of this evaluation was to collect, review, and synthesize peer-reviewed, scientifically defensible data related to restoration of wetland and riparian systems from previous agricultural land use in the MAV. Queries were entered in Google Scholar using an adaptive search technique where search terms were modified based on the relevance of responses. Relevance was assessed based on the following criteria:

Study site included restored wetland or riparian systems that were formerly in agricultural land use;

Methods included the collection of quantitative data for measuring water quality outcomes, including water quality data and soil data;

Methods included the modeling of water quality outcomes using related input data (e.g. land use, hydrology, literature-derived removal rates, etc.) in the absence of quantitative data collection;

Study location within the LMVJV region (MAV, Lower Mississippi River Basin, Lower Mississippi Alluvial Valley, and/or associated individual states);

Study site located within the Upper Mississippi with outcomes that may be interpreted for applicability to the MAV; and

Study purpose seeks to understand the drivers of variability in restoration outcomes in floodplain systems along the Mississippi River.

A total of 65 publications were collected and reviewed for further synthesis. Thirty-eight (38) publications were ultimately deemed of low relevance to this review. The remaining publications were further reviewed for synthesis and reporting of the following information:

- Classification of wetland restoration or floodplain forest/riparian restoration;
    - Classification of specific wetland type (e.g. bottomland hardwood forest, emergent marsh, etc.) and understanding of vegetation communities;
- Water quality results;
- Soil testing results related to nutrient processing capacity/rates;
- Modeling results;
- Loadings to the restored system from the surrounding watershed;
- Hydrologic regime, including frequency of flooding and residence time; and
- Time since restoration.

Research Trends

State of the Science

The restoration effort in the MAV has achieved extensive results across the landscape, with the overarching goal focused on restoring the most area for the least cost and enrolling relatively large areas of land in conservation easements (Gardiner & Oliver, 2005). While this approach has accomplished a large area of acres restored, other elements that inform future efforts and measure success, such as water quality monitoring and vegetation monitoring over ecologically relevant timescales, are largely absent from restoration programs. Researchers have recognized the need to collect these data for almost 20 years; however, progress has not been accelerated (Faulkner et al., 2011; Gardiner & Oliver, 2005;

Keerthi & Johnson, 2019a; Kröger et al., 2012; Mitsch et al., 2005). Of the 25 publications considered most pertinent to this review, approximately 50% reported water quality and/or soil testing results relevant to water quality outcomes.

Recent Research Focus Areas

More recent publications rely on water quality modeling to characterize restoration water quality outcomes. Many of these publications were not included in this review as the specificity of the exercise or variables used were not relevant to the goals of the review. However, a relevant example of reliance on modeling includes the approach used by the USDA. To quantify the benefits of conservation practices for selected conservation programs authorized through the Farm Security and Rural Investment, the USDA implements the Conservation Effects Assessment Project (CEAP). As part of this project, several regional- and watershed-scale studies have been conducted to quantify effects of ecosystem services such as water quality improvements provided by wetlands on agricultural landscapes.

Of the studies that collect water quality data, there is a focus on a) quantifying water quality improvements at a watershed scale, and b) understanding water quality outcomes along the continuum of restoration age and ecological succession. Both approaches aim to understand how restoration impacts water quality in the region now and in the future. While these are important endeavors, there appears to be many questions remaining pertinent to optimizing restoration for the desired outcomes. Several of these questions are further discussed in following sections.

Water Quality Benefits of Restoration

Monitoring Studies

The Beasley Lake Watershed located in western Mississippi is one of the 14 watersheds monitored as part of USDA's CEAP. Approximately 12% (279 ac) of the watershed was converted from cropped land to CRP (forested) beginning in 2003, and the remainder of the cropland is still managed for soybean, cotton, or corn production (Cullum et al., 2009). The watershed is considered a location representative of typical topography and cropping systems in the Mississippi Delta region. When comparing runoff and water quality over 3 years (2005 to 2008) from edge-of-field drainage sites with row crop management practices to drainage from CRP sites, Cullum et al. (2009) found that water samples from runoff in the CRP areas were 83% lower in NO2-N, 71% lower in NO3-N, 35% lower in NH4-N, 36% lower in PO4-P, and 35% lower in TP when compared to the cropped areas. Other researchers have observed consistently decreasing concentrations of TSS and TP at the Beasley Lake Watershed since the implementation of various efforts to improve water quality, including CRP (Lizotte et al., 2021).

Other studies have extrapolated soil data to estimate water quality improvements from restoration. At Mollicy Farms, a 16,000-ac bottomland hardwood forest restoration site in in the Upper Ouachita National Wildlife Refuge in northern Louisiana, an approximately 8-km river segment of floodplain restoration was estimated to remove approximately 48.1 Mg of NO3-N from the Ouachita River annually (Hurst et al., 2016).

The USACE – Vicksburg District conducts restoration activities in the Lower Mississippi Alluvial Valley to offset unavoidable impacts to bottomland hardwood wetlands. The USACE Engineer Research and Development Center (ERDC) has conducted ongoing monitoring following the development of restoration sites in the 1990s, with the projects reclaiming bottomland hardwood forests previously converted to agriculture. Monitoring efforts use hydrogeomorphic monitoring data to measure the ability of restored sites to cycle nutrients, amongst other measures of ecosystem function and services. Using this metric, restored sites displayed significant increases in nutrient cycling since 1991, with 20- and 25- year restoration intervals noticeably increasing (Berkowitz et al., 2018).

Water quality outcomes from natural systems in the region may serve as a restoration goal or anticipated endpoint of ecological succession. One such example is the well-studied Barataria Basin, located between the Mississippi River and Bayou Lafourche. Transect data from swamp bayous in the Upper Barataria Basin clearly show that TSS and nutrient concentrations from agricultural runoff decrease rapidly as flow moves through wetlands (Day et al., 2021). Swamp forest bordering Bayou Chevreuil, which receives high volumes of agricultural runoff, was found to provide strong uptake of NO3 (87%) and NH4 (33%) and release of PO4, organic N, and organic P – indicating removal and transformation of nutrients by the swamp (Day et al., 2021). Research using over 25 years of inflow versus outflow monitoring data in the Atchafalaya River Basin found that the wetland system reduced TKN by approximately 24% and TP by approximately 29% (Xu, 2013). The wetland acted a source of nitrate-nitrite, loading on average 6.5% more than the inflow concentrations due to seasonal biogeochemical processes and nitrogen transformations (Xu, 2013).

Analyzing wetland soils for parameters indicative of nutrient processing can provide a more long-term understanding of water quality improvement capacity as opposed to the snapshot provided by water quality results. This approach has been taken by several researchers seeking to understand the controls on restoration water quality outcomes in the region. Wetlands provide a wide range of nutrient processing provisioning, with rates controlled by hydrology, plant communities, climate, and other variables. As such, the processes that control water quality and the resulting water quality measurements themselves are not directly applicable from one system to another without accounting for these variables.

At the CEAP Beasley Watershed, a comparison of forested wetland soils and agricultural soils found that forested wetland soils had a denitrification potential three times greater than agricultural soils with a similar landscape position (Ullah & Faulkner, 2006). While this represents a potential improvement in water quality, research at the Beasley Watershed and at Mollicy found that restored sites had lower denitrification potential/nitrate reduction rates than control natural bottomland forests (Hurst et al., 2016; Ullah & Faulkner, 2006). Areal NO3- reduction rates in restored soils averaged 11.8 ± 3.37 mg N m−2 d−1, approximately 28% less than the control site (Hurst et al., 2016). Lower NO3- reduction rates in restored soils were associated with lower TC and TN compared to soils under natural conditions. In the Upper Mississippi, denitrification rates have been compared between natural and restored riparian buffers and depressional wetlands as well as agricultural fields. Varying conditions and mean surface organic C was found to result in significantly greater denitrification rates in natural and restored riparian buffers relative to restored depressional wetlands and agricultural fields (Marton et al., 2014a).

The USACE-restored bottomland hardwood forests are assessed using the hydrogeomorphic monitoring approach, which does not obtain laboratory analytical measurements of soil or water parameters. Rather, relevant assessment variables include measures of soil O horizon and A horizon thickness. The O horizon contains primarily organic material and plays host to several important organisms that contribute to nutrient cycling. As such, O horizon thickness is a valuable proxy for nutrient cycling provisioning. In the systems monitored by USACE, O horizon development displayed increases over the restoration chronosequence, with significant differences at 25 years post-restoration (Berkowitz et al., 2018).

Values Derived from Modeling

A number of models have been developed over the decades to simulate water quality outcomes at different spatial scales. At the larger end of the spatial scale, the Economic Research Services developed a model to understand how to achieve nutrient loading reductions to the Gulf Coast largely associated with USDA conservation practices. Data from CEAP is largely used to populate variable values; however, the water quality benefits of the wetland conservation practice are based on literature-derived values. This model assumes a wetland N removal rate of 40% and a P (as particulate matter) removal rate of 20% and a riparian buffer N (as particulate matter) removal rate of 20% and a P (as particulate matter) removal rate of 20% (Marshall et al., 2018). At the smaller project-level scale, the USDA Environmental Policy Integrated Climate (EPIC) model has been used to value water quality improvements from WRP enrollment as avoided loss (loading) of nitrate that would otherwise leach from agricultural sites (Jenkins et al., 2010).

Interpreting Restoration Water Quality Outcomes at Scale

Watershed Loads

USDA has estimated through CEAP that the Lower Mississippi River Basin contributes 400 million pounds of nitrogen and 75 million pounds of phosphorus in addition to the load upstream to the Gulf of Mexico (USDA, 2013). Treatment wetlands specifically aimed at improving water quality utilize multiple design parameters to optimize wetland performance. One such parameter is chemical loading, the amount of chemicals transported into the wetland with the flow of water. Loading rates can be estimated by existing data for loading versus removal, or through measurements of retention rates in soils. Often these data are modeled through a mass-balance approach such as the “k-C* model”, where chemical concentration, areal removal rate, and the background concentration are used to optimize wetland size and flow rate. When chemical loadings are near background concentrations, the treatment performance of the wetland is low. Multiple studies have concluded that low chemical loadings have resulted in similar nutrient concentrations in restored wetland and cropland systems (Ardón et al., 2010; Shrestha et al., 2017). In larger watersheds, conservation practices not targeted at critical sources/pathways of contaminants resulted in diminished water quality improvements (Tomer & Locke, 2011).

Applicability of Literature Values to LMVJV Region Restoration Outcomes

Of the many variables important to interpreting and applying study results towards a specific activity or region, in this case agricultural restoration in the LMVJV, three major factors were found to be of greatest importance: restoration age, management and tradeoffs, and hydrology.

Restoration Age

Variables important to biogeochemical processing and water quality provisioning are highly dependent on time since restoration. Above and belowground biomass and soil carbon take time to develop and accumulate, especially in forested systems. Several studies have attributed poor water quality outcomes from restoration as a result of the young age of the restored system (Faulkner et al., 2010; Marton et al., 2014a; Tomer et al., 2014). Others have monitored the performance of restored wetlands over time and found continued improvement in water quality provisioning with age (Berkowitz et al., 2018; Jenkins et al., 2010). Peak water quality performance, as measured by denitrification rate, appears to require a lifetime or approximately 100 years to develop without measures to accelerate carbon accumulation (Berkowitz et al., 2018; Jenkins et al., 2010; King et al., 2006; Ullah & Faulkner, 2006). Water quality outcomes within the LMVJV region resulting from restoration should be carefully interpreted and extrapolated considering the type of system (e.g. forested versus herbaceous) and the time since restoration.

Management and Tradeoffs

The many ecosystem services offered by wetlands are not always positively associated with one another. Depending on the overarching goals of restoration, one service may be diminished in favor of optimizing another. Mean soil P sorption and denitrification rates in WRP and CRP restoration sites in the Glaciated Interior Plains were found to be lower when compared to natural systems as a result of burning every 1 to 2 years to encourage habitat biodiversity (Marton et al., 2014b). In this example, management activities of the restored site favored plant biodiversity at the cost of carbon sequestration. Additionally, a restored wetland may offer conditions optimal for removing a specific chemical but not for others that may be of additional concern. These factors should be evaluated when developing a restoration plan and management plan for post-restoration maintenance to ensure that outcomes perform as originally anticipated.

Hydrology

Hydrology plays an important role in several factors related to water quality outcomes, including plant survival, nutrient loading, soil carbon development, nitrification, denitrification, and soil sorption/desorption processes. Unfortunately, current conservation practice guidance limits the ability of wetland conservation practices to effectively target the hydrologic requirements of these outcomes (Faulkner et al., 2011). Without targeted hydrologic restoration, water quality outcomes tend to be reduced. Higher denitrification potential in WRP sites has been associated with hydrologic restoration (Hunter & Faulkner, 2001) and higher retention rates of organic nitrogen and TP have been associated with optimal inflows (Xu, 2013). A lack of flood-pulse hydrology has been associated with higher plant mortality and lower productivity (Day et al., 2021) and low ammonium removal rates, and at times, net increases in ammonium at the outflow (Ardón et al., 2010).

Data Gaps and Recommendations

It is difficult to assess the success of restoration and total benefit of converting underperforming agricultural land to natural systems in terms of water quality outcomes in the LMVJV region. Current analyses using the Beasley Lake CEAP watershed data do not characterize the water quality outcomes of the individual activities that have been conducted at the site such as CRP alone. Existing CEAP data may be further analyzed in the future to further understand water quality trends and drivers at Beasley Lake and potentially associate outcomes with individual activities. Additionally, while multiple studies focused on the outcomes of various other conservation practices and BMPs, few studies focus on the measuring of wetland restoration outcomes. This likely has to do with the landscape scale of wetland restoration and difficulties ascertaining nonpoint sources (inflows) and outflow points, as well as a lack of data preceding conservation practice implementation.

Models relating water quality outcomes with restoration in the LMVJV region should be interpreted with caution. A lack of site and program-specific data for use in these models can produce results that are not necessarily representative of conditions on the land. Further water quality and soil data collection on this research topic is necessary to better inform decision-making through sound science, assess and communicate outcomes, and parameterize models (Gardiner & Oliver, 2005; Keerthi & Johnson, 2019b; Kröger et al., 2012; Mitsch et al., 2005).

When considering monitoring data, all data collected from restored sites should be interpreted with respect to restoration age. The age of restored sites distorts the interpretation of restoration success for improving water quality. It may be beneficial to revisit previous study sites to provide updated information on ecological succession and provisioning trajectories.

To optimize restoration water quality outcomes, the selection and conversion of marginal agricultural land should incorporate an analysis of existing related data (e.g. water quality, hydrology, loading, land use) to evaluate suitability and site prioritization (Barnett et al., 2016). Similarly, various entities from the programmatic level to practitioners can benefit from evaluating how objectives and the provisioning of ecosystem services may conflict. These considerations should be incorporated into site identification and prioritization to maximize desired outcomes. Clearly articulating the goals of program decisions, measuring those goals, and documenting trade offs is important for assessing success and future direction.

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