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TREE ESTABLISHMENT IN RESPONSE TO HYDROLOGY AT IDOT WETLAND MITIGATION SITES

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16. Abstract

The Illinois Department of Transportation (IDOT) has compensated for unavoidable impacts to wetlands in transportation project corridors by restoring and creating wetlands throughout Illinois. As part of the IDOT Wetlands Program, monitoring of performance measures is conducted by the Illinois Natural History Survey (INHS) and the Illinois State Geological Survey (ISGS). The goals of this research were to determine the effect of flood events on the establishment of planted and naturally recruiting trees in IDOT mitigation wetlands and to make specific recommendations for tree planting and the establishment of mitigation performance standards. We compiled and analyzed existing data from INHS and ISGS monitoring reports and conducted additional field surveys to determine long-term planted tree survival and assess natural tree recruitment. Based on our compilation of data from INHS wetland monitoring reports, we determined that the number of planted trees alive at mitigation wetlands by the end of mitigation monitoring was, on average, 57% the number of trees planted originally. We revisited ten older mitigation wetlands in 2014 and recounted surviving planted trees, and found that survival rate continued to decline beyond site monitoring periods. Tree mortality was clearly related to site exposure to flood disturbance during individual years, through the end of site monitoring, and beyond site monitoring periods. Depth and duration of inundation were more important than flood frequency in determining tree survival. Natural colonization greatly exceeded planting in terms of both stem density and basal area. However, natural colonization was not clearly related to site flood exposure. In sites that are exposed to long-duration or deep flooding, planted tree survival is likely to be low regardless of species planted or the degree of on-site management of plantings. We recommend that realistically attainable mitigation performance standards be developed on a site-specific basis, considering the likely hydrologic regime of the site. In some situations, faster-growing species provide tangible environmental benefits. In addition, natural tree colonization can supplement planting, even in sites where planted hard-mast species are unlikely to persist.

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EXECUTIVE SUMMARY

Section 404 of the U.S. Clean Water Act, which is enforced by the U.S. Army Corps of Engineers, requires a permit for the deposition of dredge or fill materials into waters of the United States, including wetlands. Filling a wetland may be permitted if wetland impacts are unavoidable, but the permittee must compensate for wetland impacts by restoring, creating, or enhancing wetlands elsewhere. These “compensatory mitigation wetlands” must be monitored for a period of 5 years or more to determine if they meet a set of performance standards. Standards for forested mitigation wetlands are often based on survival of planted trees. Mitigation agreements and performance standards demonstrate a clear preference for the use of hard-mast tree species such as such as oaks (*Quercus* spp.) and hickories (*Carya* spp.), which are valuable or wildlife and do not readily recolonize. However, wetland mitigation in floodplain areas can be particularly challenging due to disturbances from frequent or prolonged flooding. Prolonged inundation promotes the establishment of wetland plant species, but planted trees, even those tolerant of intermittent flooding, suffer high mortality with prolonged inundation during the growing season. Hard-mast tree species, in particular, are often difficult to establish. As a consequence, tree survival criteria are often unmet in compensatory mitigation wetlands that are exposed to deep or long-duration flooding, and the party responsible for mitigation must replant trees at great expense to achieve compliance.

The Illinois Department of Transportation (IDOT) has compensated for unavoidable impacts to wetlands in transportation project corridors by restoring and creating wetlands throughout Illinois. As part of the IDOT Wetlands Program, monitoring of performance measures is conducted by the Illinois Natural History Survey (INHS) and the Illinois State Geological Survey (ISGS). After initial wetland restoration and/or creation activities are complete, vegetation and soils data are collected by the INHS, and hydrologic and topographic data are collected by the ISGS, to monitor for attainment of wetland criteria and performance standards. The goals of this research were to determine the effect of flood events on the establishment of planted and naturally recruiting trees in IDOT mitigation wetlands and to make specific recommendations for tree planting and the improvement of mitigation performance standards. Our specific objectives were to (1) relate planted tree survival rates at IDOT wetland mitigation sites to flooding history using legacy data from the IDOT Wetlands Program; (2) continue an ongoing study, initiated in 2012, to track the survival of individual planted trees at newly established IDOT mitigation wetlands; (3) revisit older (>10 years) IDOT mitigation wetlands and reassess planted tree survival to relate long-term planted tree establishment to long-term site hydrologic regimes; and (4) establish plots in IDOT wetland mitigation sites to determine natural recruitment rates of floodplain trees in different hydrologic settings.

Planted tree survival was generally low in compensatory mitigation wetlands, even after replanting. Based on our compilation of data from INHS wetland monitoring reports, we determined that the number of planted trees alive at mitigation wetlands by the end of mitigation monitoring was, on average, 57% the number of trees planted originally. We revisited ten older mitigation wetlands in 2014 and recounted surviving planted trees, and found that survival rate continued to decline beyond site monitoring periods. Tree mortality during individual years was significantly greater in mitigation wetlands with greater exposure to flood disturbance. Furthermore, tree mortality through the end of site monitoring was greater in wetlands with greater average annual flood exposure. We also assessed natural colonization by trees at 13 mitigation wetlands in 2014. Natural colonization exceeded planting in terms of stem density, basal area, and number of species. However, species composition differed between naturally colonizing trees and planted trees. Naturally colonizing trees tended to be light-seeded and wind-dispersed species, whereas planted trees were often hard-mast species. Natural colonization was not related clearly to site flood exposure.

Based on this research, we make the following recommendations for implementing mitigation. First, tree survival at mitigation wetlands can be improved by planting appropriate species in appropriate locations. We recommend monitoring hydrology for at least one year at proposed mitigation sites prior to tree planting in order to identify appropriate planting locations within and among sites. Second, we recommend planting larger individuals, which are less susceptible to flood stress. However, in sites that are exposed to long-duration or deep flooding, planted tree survival is likely to be low regardless of the species planted or the degree of on-site management of plantings. Given the poor survival of hard-mast tree species and the clear relationship between flooding and planted tree mortality, it is unrealistic to expect that slow-growing species such as oaks and pecans can be successfully established at all mitigation wetlands. We recommend that realistically attainable mitigation performance standards be developed on a site-specific basis, considering the likely hydrologic regime of the site. In some situations, faster-growing species provide tangible environmental benefits. In addition, natural tree colonization can supplement planting, even in sites where planted hard-mast species are unlikely to persist.

CONTENTS

CHAPTER 1 INTRODUCTION

Since the 1780s, approximately half of the original wetland area in the conterminous United States has been converted to other land uses (Dahl 2000). Midwestern states, in particular, have lost a large proportion of their original wetland area. Wetland drainage in Illinois exceeds 90% (Suloway and Hubbell 1994). In response to the dramatic loss of wetland area and associated ecosystem functions, federal, state, and local governments have implemented policies with a goal of restricting additional wetland loss (Brown and Lant 1999, Hough and Robertson 2009). At the federal level, Section 404 of the Clean Water Act, which is enforced by the U.S. Army Corps of Engineers (USACE), prohibits the deposition of dredge or fill materials into waters of the United States, including wetlands. The current national policy goal is “no-net-loss” of wetland area and function (Federal Register 2008). Filling a wetland may be permitted if wetland impacts are unavoidable, but wetland destruction must be compensated for through restoration, creation, or enhancement of wetlands elsewhere. These compensatory mitigation wetlands are typically required to meet a set of site-specific performance standards approved by USACE, usually within a five-year monitoring period (NRC 2001). Performance standards allow regulators to evaluate if mitigation projects are meeting objectives (Streever 1999, Federal Register 2008).

State departments of transportation, to comply with state and federal environmental regulations, seek to avoid or minimize environmental impacts within transportation project areas. Unavoidable impacts to wetlands must be compensated for through the restoration or creation of wetlands. Compensation can come in the form of permittee-responsible wetland mitigation, purchase of credits from an approved wetland mitigation bank, or payments to an approved in-lieu-fee wetland program (Hough and Robertson 2009). In the case of permittee-responsible mitigation, the creation, restoration or enhancement of wetlands or streams is performed by the permittee, or a contractor hired by the permittee, to compensate for impacts resulting from a specific project. With mitigation banks, which are designed to compensate for multiple development projects, a third-party mitigation banker undertakes the restoration, creation, enhancement, or preservation of wetlands or streams, and credit for that compensation is purchased by the permittee. Departments of transportation perform permittee-responsible mitigation, and some departments, including the Illinois Department of Transportation (IDOT), have developed in-house mitigation banks to compensate for impacts from multiple transportation projects.

A compensatory mitigation wetland is considered to be a success if, after a specified monitoring period, the site meets all performance standards stated in a permit or agreement between the regulatory agencies and the permittee. Performance standards have been based on biological metrics, such as characteristics of plant, invertebrate, or fish communities, or abiotic metrics such as hydrologic regime or soil characteristics (ELI 2004). USACE District Engineers have broad discretion in developing performance standards for their districts (Urban 2008). Performance standards are included as conditions in Section 404 permits and determine how a site will be monitored. A site may fail to meet performance standards for one of two major reasons. First, performance standards are unlikely to be met if restoration is implemented or designed poorly, for example if mitigation providers do not establish appropriate wetland hydrology or manage invasive plant species (Brown and Veneman 2001, Morgan and Roberts 2003, Matthews and Endress 2008). Second, performance standards will not be met if those standards were not realistically achievable given the site’s size, land use history, or spatial context within a watershed. Several authors have pointed out the importance of establishing measurable, realistically achievable, and scientifically based performance standards for compensatory wetland mitigation projects (NRC 2001, Cole 2002, Martin et al. 2005, Matthews and Endress 2008).

To improve the wetland compensation process, in 2008 the U.S. Environmental Protection Agency (USEPA) and the USACE issued updated rules for wetland compensation that clarified the use of ecological performance standards. The new rules require that mitigation plans contain ecological performance standards defined as "…observable or measurable physical (including hydrological), chemical and/or biological attributes that are used to determine if a compensatory mitigation project meets its objectives" (Federal Register 2008, p. 19672). Additionally, the Final Rule outlines other principles for ecological performance standards such that they need to be objective and verifiable, based on best available science, and *consider hydrologic variability* (Federal Register 2008). The rule also allows for some flexibility for developing performance standards to account for wetland (or other aquatic resource) type and geographic region (Federal Register 2008).

Impacts to forested wetlands are typically compensated "in-kind," meaning that compensatory mitigation wetlands must also be forested. Bottomland forests are often restored on former agricultural lands along rivers and streams. Restoration of agricultural bottomland requires restoration of hydrological flows through removal of existing drainage features (e.g., drain tiles or ditches) and water control structures (e.g., levees), shallow excavation to intercept ground water, or redirection of water onto the site. Initial hydrologic restoration is followed by planting of flood-tolerant tree species. Mitigation agreements and performance standards demonstrate a clear preference for the use of hard-mast tree species such as such as pin oak (*Quercus palustris*), swamp white oak (*Q. bicolor*), and pecan (*Carya illinoiensis*). Performance standards for these sites may specify a minimum percentage for tree survival or a minimum stem density (i.e., number of surviving trees per unit area) by the end of the monitoring period. However, planted tree survival is often poor and many sites fail to achieve their performance standards (Jarman et al. 1991, Pennington and Walters 2006, Matthews and Endress 2008). Mitigation wetlands that do not meet tree survival criteria are deemed unsuccessful by regulatory agencies, and the party responsible for mitigation must replant trees, often at great expense, to achieve compliance.

Wetland mitigation in floodplain areas can be particularly challenging due to disturbances from frequent or prolonged flooding. Planted trees, even those tolerant of intermittent flooding, suffer high mortality with prolonged inundation during the growing season (Pennington and Walters 2006). Saturation of the root zone prevents oxygen from reaching root tissues, leading to reduced root and shoot growth, root decay, and eventually plant mortality (Kozlowski 2002). Other stressors associated with flooding include sedimentation and mechanical disturbance from floating ice and debris (Bendix 1999, Bendix and Hupp 2000, Hughes et al. 2001, Richardson et al. 2007). Despite broad recognition that hydrology is a primary determinant of the structure and function of wetlands, the effect of hydrology on the achievement of vegetation-based performance standards is often ignored. The goals of this study were to determine the effect of flood events on the establishment of planted and naturally recruiting trees and to make specific recommendations for tree planting and the improvement of mitigation performance standards.

As part of the IDOT Wetlands Program, monitoring of performance measures is conducted by the Illinois Natural History Survey (INHS) and the Illinois State Geological Survey (ISGS). After initial wetland restoration and/or creation activities are complete, vegetation and soils data are collected by the INHS, and hydrologic and topographic data are collected by the ISGS, to monitor for attainment of wetland criteria and performance standards. These data not only provide documentation for regulatory compliance but also provide a unique opportunity to examine, in detail, the ecological performance of a large number of compensatory mitigation wetlands in a wide range of hydrologic settings. This study draws on past and current monitoring data acquired through the IDOT Wetlands Program and consists of four specific objectives:

1. Relate planted tree survival rates at IDOT wetland mitigation sites to flooding history using legacy data from the IDOT Wetlands Program. We hypothesized that annual mortality of planted trees would be positively correlated with flood exposure.
2. Continue an ongoing study to track the survival of individual planted trees at newly established IDOT mitigation wetlands to relate survival to species and flooding depth and duration.

3. Revisit older (>10 years) IDOT mitigation wetlands and reassess planted tree survival to relate long-term planted tree establishment to long-term hydrologic regimes. We hypothesized that long-term planted tree survival would be lower in restored floodplain forests that were subject to frequent, deep, or long-duration flood events.
4. Establish plots in IDOT wetland mitigation sites to determine natural recruitment rates of floodplain trees in different hydrologic settings. We hypothesized that the species composition and density of naturally recruiting trees would vary with hydrologic regime among restored floodplain forests.

CHAPTER 2 LITERATURE REVIEW

2.1 EFFECTS OF FLOODING ON TREE GROWTH AND MORTALITY

Wetland ecosystem structure (e.g., species diversity, species composition, and physical habitat structure) and function (e.g., nutrient and energy fluxes) are determined primarily by the hydrologic regime—the depth, frequency, duration, and seasonality of inundation (Wilson and Keddy 1985, Bendix 1997, Sluis and Tandarich 2004, Turner et al. 2004, Nygaard and Ejrnæs 2009). Waterlogged soil, and associated soil anoxia, is a primary environmental constraint for wetland biota. Plant cells require oxygen for aerobic respiration, and plant roots must acquire oxygen from air in soil pores. Upon flooding, however, oxygen in soil pores is rapidly consumed by plant roots and microorganisms and is not readily resupplied from the atmosphere due to the slow rate of oxygen diffusion through water (Keddy 2010). Wetland plants have several adaptations that allow them to tolerate anoxic soil conditions (Cronk and Fennessy 2001, Kozlowski 2002, Glenz et al. 2006). Nevertheless, long-duration or deep flooding is a stress for wetland plants, especially for woody plants that occupy sites that are usually only intermittently or infrequently inundated. Long periods of anoxia lead to the death of roots, reduced mycorrhizal biomass, loss of leaves, severely reduced photosynthetic rates and growth, reduced or forestalled reproduction, and eventually, plant mortality (Kozlowski 2002, Glenz et al. 2006). Tree seedlings can establish in areas that are temporarily flooded, and forested wetlands can develop, but as the frequency or duration of flooding increases, forested wetlands transition to emergent wetlands that are dominated by flood-tolerant herbaceous species (Toner and Keddy 1997). Prolonged flooding limits seed germination and seedling establishment. Seedlings, because they are often completely inundated, are more susceptible to flooding than adult plants (Broadfoot and Williston 1973). Experimental studies have reported reduced survival, net biomass, and height for tree seedlings grown in permanently inundated soils compared with those grown in moist soils (Wallace et al. 1996, Battaglia et al. 2000). Consistent with these experimental findings, tree seed germination and seedling establishment at low elevations in forests are constrained by flooding (Middleton 2000). As a consequence, hydrologic regime determines the boundary between forested and emergent wetlands (Toner and Keddy 1997).

Mature trees, although more tolerant of flooding than seedlings, suffer increased mortality as a result of flooding. Tree mortality is greater in sites with greater exposure to flooding (Acker et al. 2003, Ernst and Brooks 2003, Howard 2012). However, mortality tends to be episodic rather than continuous—mortality may be low in most years, but it rises sharply in flood-exposed sites during years with extreme flooding (Yin 1998, Acker et al. 2003, Damasceno-Junior et al. 2004). For example, Yin et al. (2009) reported that the 1993 flood on the Mississippi River resulted in a 57% decrease in of the number of trees and a 33% decrease of total tree basal area in Upper Mississippi River floodplain study sites. Relationships between tree growth and flooding are complex, however. Although floods during the growing season are stressful for trees, floods deliver nutrient-laden sediment, which may stimulate tree growth following flooding (Mitsch and Rust 1984).

2.2 EFFECTS OF FLOODING ON FOREST COMMUNITY COMPOSITION

Tree species differ in tolerance to flooding due to differences in adaptations to tolerate or recover from waterlogging (Hook 1984). Thus, hydrology acts as a filter on species composition because few species can tolerate the wettest conditions (Mitsch and Gosselink 2007, Conner et al. 2002). For example, sites on the Upper Mississippi River floodplain that were flooded for longer than 40% of the growing season were almost entirely dominated by silver maple (*Acer saccharinum*) and had low overall woody diversity (De Jager et al. 2012). Several studies have shown that flood exposure, or elevation relative to a nearby river or stream, is a strong predictor of woody species composition in floodplain forests (Hall and Harcombe 1998, Bendix 1999, Battaglia et al. 2002, Turner et al. 2004, Loučková 2012).

A major flood event can alter tree species composition by removing species that are less tolerant of inundation and by creating conditions for new species to establish after the flood event. For example, species that typically grow on floodplain terraces, such as elms (*Ulmus* spp.), sugarberry (*Celtis laevigata*), honey locust (*Gleditsia triacanthos*), and persimmon (*Diospyros virginiana*), died during the second year of continuous, shallow inundation in a Mississippi floodplain forest, whereas more tolerant species, such as green ash (*Fraxinus pennsylvanica*) and overcup oak (*Quercus lyrata*), survived until the third year of flooding (Broadfoot and Williston 1973). Flood disturbance sets back ecological succession and allows establishment of new species in floodplain communities. Floods destroy existing vegetation and deposit fresh sediments that provide new sites for seed germination and seedling establishment (Naiman and Décamps 1997, Bendix and Hupp 2000, Richardson et al. 2007). After agricultural abandonment or natural disturbances such as major floods, early development of forested wetlands is dominated by a few species of light-seeded, easily dispersed trees such as willows (*Salix* spp.) and eastern cottonwoods (*Populus deltoides*) (Middleton 2003, Yin et al. 2009). Flowing waters also deliver dispersing plant propagules to sites, facilitating colonization by new species (Andersson et al. 2000, Middleton 2000, Leyer 2006).

2.3 TREE SURVIVAL IN FORESTED WETLAND RESTORATIONS

Floodplain wetlands are often targeted areas for restoration because they provide an array of valuable ecosystem services including biodiversity support, flood abatement, water quality improvement, fisheries support, and sediment retention (Mitsch and Gosselink 2007). However, current approaches to floodplain restoration often ignore extreme hydrologic variability, consequently resulting in unexpected mortality of planted species and failure to achieve restoration goals (Pennington and Walters 2006, Pociask and Matthews 2013).

Under Section 404 of the U.S. Clean Water Act, IDOT is required to restore wetlands to compensate for wetlands impacted during transportation projects. Planted tree survival is often included as a mitigation performance standard for forested wetland mitigation projects (Breaux and Serefiddin 1999, Streever 1999, Matthews and Endress 2008). However, tree survival rates at mitigation wetlands are not well documented in peer-reviewed scientific literature. Matthews and Endress (2008), in a review of 38 mitigation projects constructed by IDOT between 1992 and 2002, found that 19 projects had performance standards requiring a minimum survival of planted trees by the end of site monitoring. Performance standards for survival percentages ranged from 50% to 100% survival, and some standards specified a minimum number of live stems per acre after 5 years. Of these 19 projects, only four met their site-specific performance standard for planted tree survival by the final year of monitoring. As a result, many of these sites were not accepted as adequate compensation by the USACE, and IDOT was required to undertake additional compensatory mitigation activities.

Planted tree survival is also low in floodplain forests that have been restored for other purposes, such as the Wetlands Reserve Program (WRP). Stanturf et al. (2004) reported that 90% of WRP plantings in Mississippi failed to meet tree survival goals. Restoration practitioners surveyed by King and Keeland (1999) frequently cited excessive flooding as a cause of reforestation failure in the Lower Mississippi River Alluvial Valley.

Despite the overriding influence of hydrologic regimes on restoration outcomes, there is currently little guidance for tailoring wetland mitigation performance standards to site-specific hydrologic conditions. Pociask and Matthews (2013) analyzed data collected by INHS and ISGS during past mitigation site monitoring to examine the ecological mechanisms that lead to variation in performance among compensatory mitigation wetlands. They evaluated the influence of flooding on ten plant-community metrics that are often used as performance standards and found that mean annual flood exposure was inversely related to three of the metrics: species richness, Floristic Quality Index, and proportion of perennial species. In direct contrast to these vegetation-based performance metrics, performance standards that require a minimum area meeting wetland hydrology or hydrophytic vegetation criteria were more likely to be met during years with major flood events. Thus, performance standards can stand in opposition to each other; as a result of flood events, a high likelihood of achieving one set of standards can mean a low likelihood of achieving a second set.

Natural colonization by species such as silver maple and green ash, as well as bottomland understory plants, augments intentional tree planting and increases overall diversity in restored forested wetlands. Therefore, restoration outcomes depend on a combination of active site manipulation and passive colonization. Species that naturally colonize restoration sites may be better adapted to the particular environmental conditions of the site than intentionally introduced species (Prach and Hobbs 2008). However, in most cases, natural tree colonization has not been assessed during mitigation site monitoring or considered in mitigation performance standards (Matthews and Endress 2008).

CHAPTER 3 METHODS

3.1 STUDY SITES

As part of the IDOT Wetlands Program, monitoring of performance measures is conducted by the Illinois Natural History Survey (INHS) and the Illinois State Geological Survey (ISGS). After initial wetland restoration and/or creation activities are complete, vegetation and soils data are collected by the INHS, and hydrologic and topographic data are collected by the ISGS, to monitor for attainment of wetland criteria and performance standards.

The initial step in this study was to assess monitoring data from past and current IDOT wetland mitigation sites. For this study, we considered 59 IDOT wetland compensation sites, established since 1992, for potential inclusion in this study. The basic criteria we used for site selection and data assessment were that (1) the site is located within a floodplain, (2) the site receives direct flooding or has a hydrology that is influenced by the flood regime of the adjacent stream, and (3) trees were planted at the site and tree survival was monitored by INHS. Further, in order to conduct the statistical analysis, only sites where the sampling period for hydrologic and vegetation data overlapped for 3 or more years were selected, and the measurement interval for water-level data needed to be collected at least daily to provide adequate resolution for the quantifying flood exposure. Of the 59 sites initially considered for the analysis, 22 sites were selected (Figure 1). Sites were monitored between 1996 and 2011, and the overlapping duration of hydrologic and tree survival monitoring ranged from 3 to 8 years after initial wetland restoration activities were completed. Contributing drainage areas for the selected sites ranged from 6.5 to ~1.8 million km^2; thus, the sites represent a wide range of drainage area and correspondingly a wide range of flood regimes. Additional information on the study sites is available in the report by Pociask and Matthews (2013).

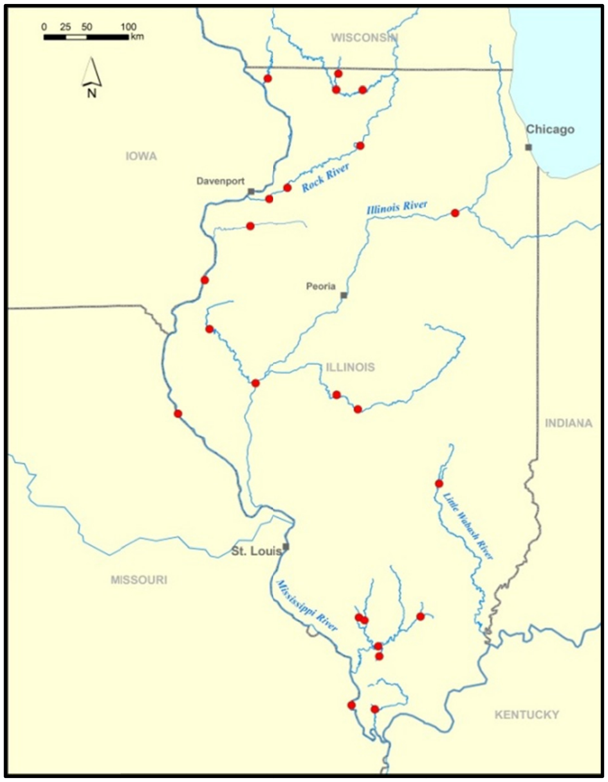

Figure 1. Map of Illinois showing the locations of IDOT wetland mitigation sites used in this study.

3.2 HYDROLOGIC MONITORING AND FLOOD EXPOSURE CALCULATION

Surface water data used for the analysis were either collected by the ISGS during wetland mitigation site monitoring or were obtained from online stream gaging databases maintained by the U.S. Geological Survey (USGS 2012) or USACE (2012). Data collected at the wetland mitigation site by the ISGS were acquired with electronic water-level dataloggers set at sampling intervals ranging from daily to hourly. At two sites, we used stage records from nearby gaging stations to develop calibration curves and applied these curves to estimate the hydrograph to supplement incomplete on-site datasets (see Toner and Keddy 1997). We used the surface water data to evaluate flood characteristics for each flood event during the monitoring period at each site. While a variety of measures have been developed and used for relating hydrologic regime to ecological variables (e.g., see Richter et al. 1996, Toner and Keddy 1997), our intent was to evaluate the frequency, depth, and duration of inundation of the wetland plant community.

We selected a threshold elevation at each site as the minimum site elevation that indicated most of the site was flooded without including hydrologic fluctuations within on-site water features (i.e., fluctuations within ponded areas). To select the threshold elevation, hydrographs were visually examined to distinguish flood events from fluctuations within ponded areas and a minimum floodplain elevation was selected to filter out hydrograph peaks that were not associated with river flooding. We defined three hydrologic metrics: (1) annual flood frequency, or the number of flood events occurring in a given year; (2) annual maximum flood depth (meters) at the threshold elevation; and (3) annual maximum flood duration (days) at the threshold elevation. In addition, we used a fourth measure of flood intensity as described in Ahmad and Ahmed (2003). However, for clarity, we use the term flood exposure index (FEI) to distinguish from other measures of flood intensity based on stream discharge (e.g., Walling and Teed 1971). The formula for FEI is given as follows:

$$\mathbf{FEI} = \boldsymbol{D_{avg}} \times \boldsymbol{R}$$

where D_{avg} is the average depth above a specified elevation threshold and R is the duration of the flood above the specified threshold elevation. The unit of FEI is meter-days. FEI was calculated for each flood event during each year of the monitoring period. We chose to use the annual maxima for FEI (FEI_{max}), flood depth, and flood duration as the independent variables for statistical analyses because these values represent the highest magnitude flood in a given year and therefore represent the flood event that has the maximum effect on planted trees at a mitigation site.

3.3 TREE SURVIVAL MONITORING AND CALCULATIONS

IDOT has restored forested wetland sites throughout Illinois, most commonly on former agricultural lands along rivers and streams. Flood-tolerant tree species are planted at these sites following the restoration of wetland hydrology. Stocking rates, size of planted trees, and tree species vary among sites. However, regulatory agencies typically require the planting of hard-mast producing tree species such as oaks (*Quercus* sp.) and pecans (*Carya illinoiensis*). INHS has been tasked with evaluating whether IDOT mitigation wetlands achieve site-specific performance standards related to vegetation establishment, including planted tree survival. Throughout the specified monitoring period for each mitigation wetland, INHS visits sites annually and tallies surviving trees by species. For this project, we compiled existing data from annual tree survival counts conducted by the INHS.

IDOT often replants trees in response to mortality. Therefore, we used two methods to calculate tree survival for each site in each year. First, we calculated the proportion of the originally planted trees surviving each year. This proportion can exceed one if, as a result of replanting, the number of surviving planted trees in a given year exceeds the number of trees that were initially planted at the site. Second, we calculated the proportion of the cumulatively planted trees surviving each year.

Results were qualitatively similar for both methods. We opted to report only the proportion of trees originally planted because it relates directly to site performance standards and because records of tree numbers and species replanted were not available for all sites.

We used mixed models (PROC MIXED in SAS 9.3 statistical software, SAS Institute Inc., Cary, NC) to evaluate the influence of annual flood disturbance on the proportion of originally planted trees surviving each year at each site. Mixed models are appropriate for data that are organized at more than one level (Singer 1998). In this case, the data are organized at two levels, with years nested within wetland sites. Site identity was included as a random factor in all models to account for underlying differences in tree survival among sites. Proportion of trees surviving each year was included as the response variable in statistical models, and annual flood frequency, annual maximum depth, annual maximum flood duration, and FEI_{max} were included as predictor variables in separate models. Annual maximum flood duration and FEI_{max} were strongly right-skewed and were log-transformed prior to analysis. Of the 22 mitigation sites used for this study, 19 were included in this analysis. Three sites were excluded from the analysis, two because we could find no record of the number of trees originally planted, and a third because INHS used subsampling instead of counting to estimate the number of surviving trees at the site. We repeated these analyses separately for individual tree species that were planted in at least 10 IDOT mitigation wetlands. These species included pecan, green ash, sycamore (*Platanus occidentalis*), swamp white oak, and pin oak.

3.4 BASELINE TREE SURVIVAL DATA COLLECTION

We initiated an experiment in 2012 to evaluate the effect of flooding on planted tree survival within mitigation wetlands. Three recently planted IDOT mitigation wetlands were selected for this project: the LaGrange Mitigation Bank in Brown County, the Weber site in Stephenson County, and the East Cape Girardeau site in Alexander County. The locations and species of all planted trees at the Weber and East Cape Girardeau sites and a subset of trees at the LaGrange site were recorded in the field using a Trimble Global Positioning System with a presumed accuracy of ± 1.6 ft (0.5 m) under optimal field conditions.

The locations and species of 1912 planted trees were recorded: 165 trees at the Weber site in Stephenson County, 1140 trees at the LaGrange Mitigation Bank in Brown County, and 607 trees at the East Cape Girardeau site in Alexander County. We revisited each site in 2013 and 2014 and recorded the condition of every previously surveyed tree. In this report, we present trends in planted tree survival through 3 years at these sites.

3.5 ASSESSMENT OF LONG-TERM PLANTED TREE SURVIVAL AND NATURAL TREE COLONIZATION

During the summer of 2014, we revisited older IDOT mitigation wetlands to assess long-term planted tree survival. We obtained tallies of originally planted trees, from files stored at the INHS, at 12 IDOT mitigation wetlands that were >10 years old. At each site, at least two people walked parallel lines approximately 33 ft (10 m) apart, back and forth across the entire site, and tallied planted trees by species. We excluded two sites from our analysis because we could not distinguish planted from naturally colonized trees.

Monitoring of vegetation and hydrology by INHS and ISGS at these older mitigation wetlands had ended by 2014. Therefore, we did not have access to hydrologic monitoring data for these sites through 2014. However, we were able to relate long-term planted tree survival to site flooding regimes by averaging hydrologic variables across all years for which hydrologic data were available. Linear regression (in SAS 9.3) was used to describe the relationship between proportion of originally planted trees surviving in 2014 and annual averages for flood frequency, maximum depth, maximum duration, and FEI_{max}.

To quantify recruitment by naturally colonizing (volunteer) trees, during the summer of 2014 we established three representative sampling transects at each of 13 IDOT mitigation wetlands that had been restored at least 10 years ago. We measured tree diameter at breast height (DBH) of all woody stems greater than 2-in (5-cm) DBH in a 33 × 164-ft (10 × 50-m) plot along each transect. Using tree tallies and DBH measurements, we calculated the stem density (number of stems per acre) and basal area (ft^2 per acre) for each planted and volunteer tree species at each site. We related density and basal area of volunteer trees to annual averages for flood frequency, maximum depth, maximum duration, and FEI_{max} using linear regression (in SAS 9.3) to determine whether unassisted tree establishment in IDOT mitigation wetlands was related to hydrologic conditions.

CHAPTER 4 RESULTS

4.1 EFFECTS OF FLOODING ON PLANTED TREE SURVIVAL DURING MITIGATION MONITORING PERIODS

For all species combined, the proportion of trees surviving in IDOT mitigation wetlands each year decreased as annual maximum flood duration and depth increased (Table 1). This decrease in survival was statistically significant ($p < 0.05$) for maximum depth but not duration. Flood exposure index (FEI_{max}), which combines both depth and duration, was the best predictor of annual tree survival (Table 1, Figure 2A). Flood frequency, calculated as the number of flood events in a year, was unrelated to survival of all species combined.

Table 1. Results of Mixed Models to Evaluate the Influence of Flood Disturbance on Annual Planted Tree Survival

		flood frequency (number of events)		maximum flood depth (m)		ln (maximum flood duration [days])		ln (FEImax [m.days])	
Dependent variable	***n*[†]**	***F***	**parameter estimate**	***F***	**parameter estimate**	***F***	**parameter estimate**	***F***	**parameter estimate**
proportion of planted trees surviving	89, 19	0.01	0.001	**4.51***	–0.051	3.12	–0.030	**8.17****	–0.049
proportion of pecan surviving	44, 10	1.78	–0.001	2.77	–0.043	**9.81****	–0.055	**14.79****	–0.066
proportion of green ash surviving	53, 11	0.28	0.007	**7.00***	–0.128	2.82	–0.060	**8.29****	–0.116
proportion of sycamore surviving	51, 10	**5.62***	–0.020	**8.09***	–0.067	**7.91****	–0.060	**8.47****	–0.066
proportion of swamp white oak surviving	77, 16	2.13	–0.012	**8.29****	–0.102	**6.16***	–0.061	**9.28****	–0.080
proportion of pin oak surviving	67, 14	**5.27***	–0.012	0.07	0.007	2.82	–0.029	0.10	–0.006

[†] First number is the total number of observations; second number is the number of independent sites.

*$p < 0.05$, **$p < 0.01$

Five tree species were planted frequently enough (at least ten sites) to analyze their survival separately. Annual proportions of surviving pecan, green ash, sycamore, and swamp white oak decreased significantly as FEI_{max} increased, indicating that these species suffered greater mortality during years with deeper and/or more prolonged flooding (Table 1, Figure 2B–E). Annual FEI_{max} was not a significant predictor of proportion of surviving pin oaks (Table 1, Figure 2F). However, annual survival of pin oaks decreased significantly as flood frequency increased (Table 1).

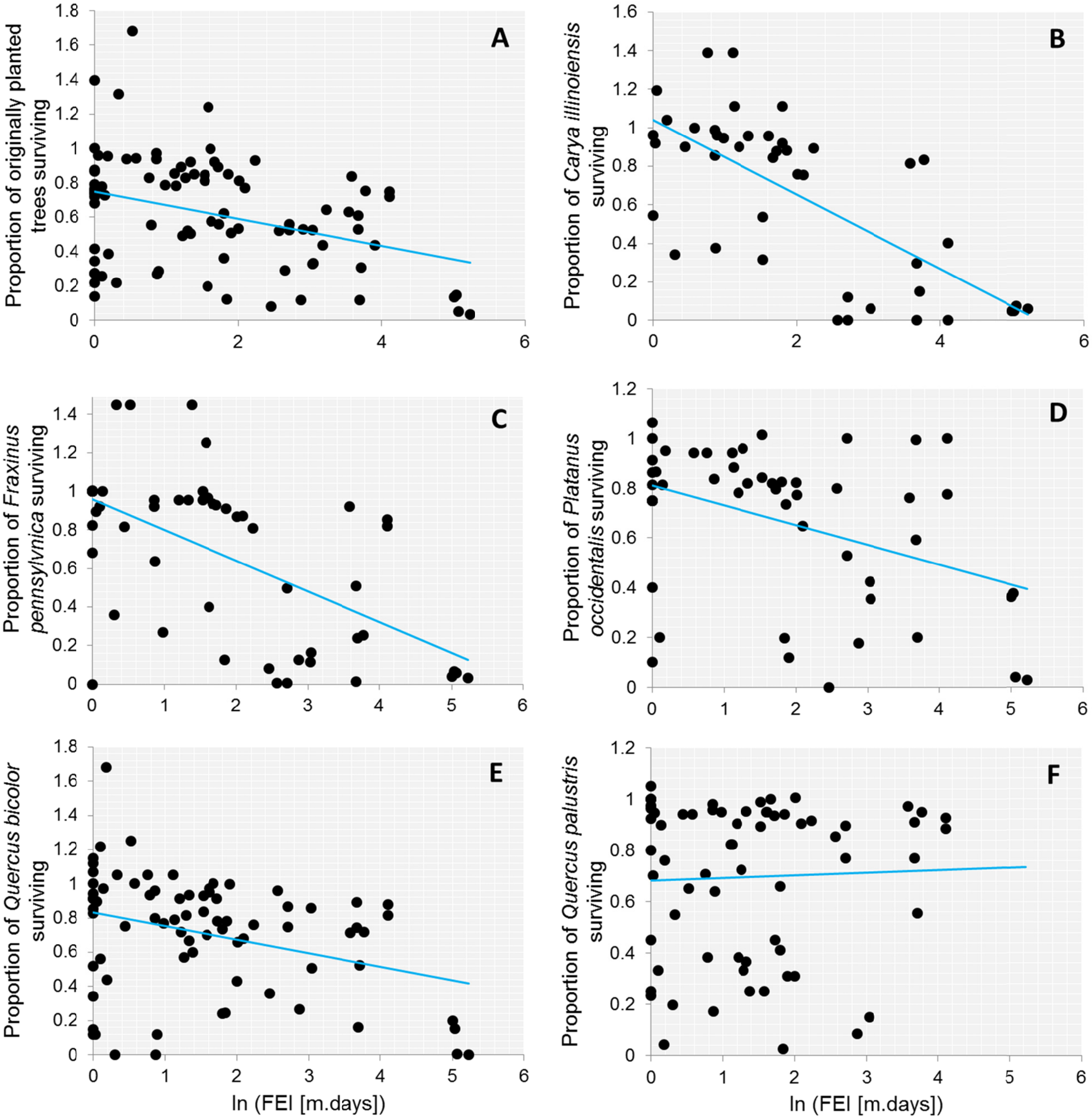

Figure 2. Annual proportion of planted trees surviving vs. log-transformed annual flood exposure index (FEI_{max}), for all planted tree species (A) and species planted at more than ten mitigation wetlands (B–F). Survival can exceed 100% due to replanting.

By the end of mitigation site monitoring by INHS, planted tree survival, relative to the initial planting, was approximately 57% across all species. Survival rates were similar across most of the frequently planted species: green ash 60%, pin oak 60%, swamp white oak 58%, pecan 57%, and sycamore 49%. Planted tree survival at the end of site monitoring was significantly lower in wetlands with greater flood exposure, calculated as FEI_{max} averaged across all years up to and including the final year of monitoring (Figure 3; $n = 18$, $F = 5.26$, $p = 0.04$).

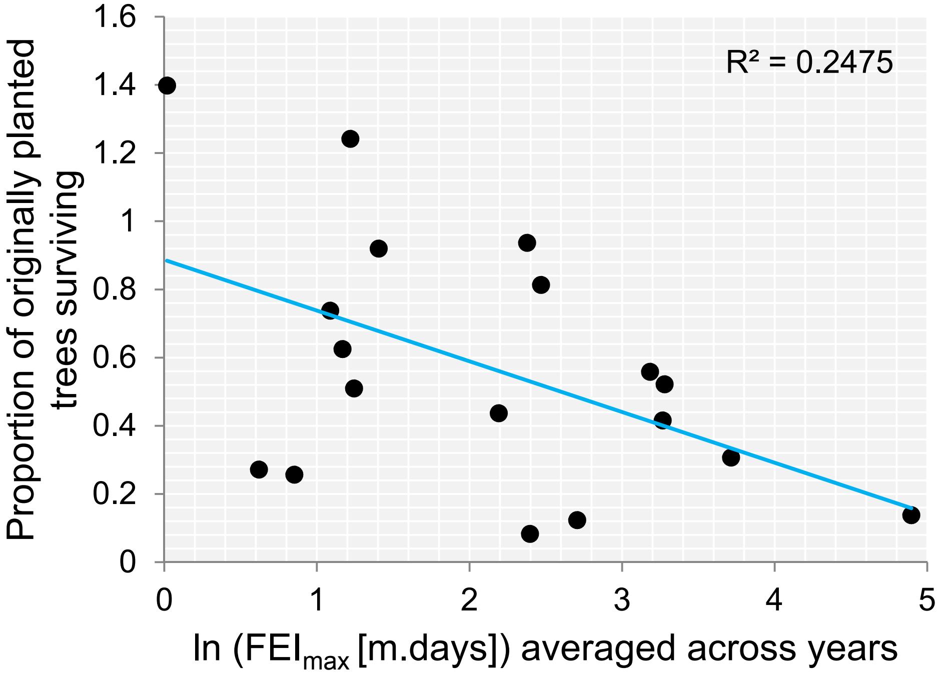

Figure 3. Proportion of originally planted trees surviving in mitigation wetlands at the end of site monitoring by INHS vs. log-transformed, average annual flood exposure index (FEI$_{max}$). Survival can exceed 100% due to replanting.

4.2 TRENDS IN PLANTED TREE SURVIVAL AT RECENTLY ESTABLISHED MITIGATION WETLANDS

Using a GPS, we recorded the locations and species of 1912 planted trees at three recently restored forested wetlands in 2012 (Figures 4a and 4b). We resurveyed these sites in 2013 and 2014 to track the survival of individual trees over time. Percent tree survival between 2012 and 2014 was 88% at the LaGrange Mitigation Bank, 92% at East Cape Girardeau, and 71% at the Weber site. Pecan mortality at LaGrange Mitigation Bank was greater than oak mortality, and exceeded 20% by 2014 (Figure 5A). In contrast, pecans survived well at the East Cape Girardeau site, where all species had at least 85% survival through 2014 (Figure 5B). Mortality of pecans and northern pin oak (*Quercus ellipsoidalis*) was high at the Weber site in 2014 (Figure 5C). Baseline maps of planted trees will be used to compare with subsequent sampling campaigns to track tree survival by species and elevation in response to future flood and drought events.

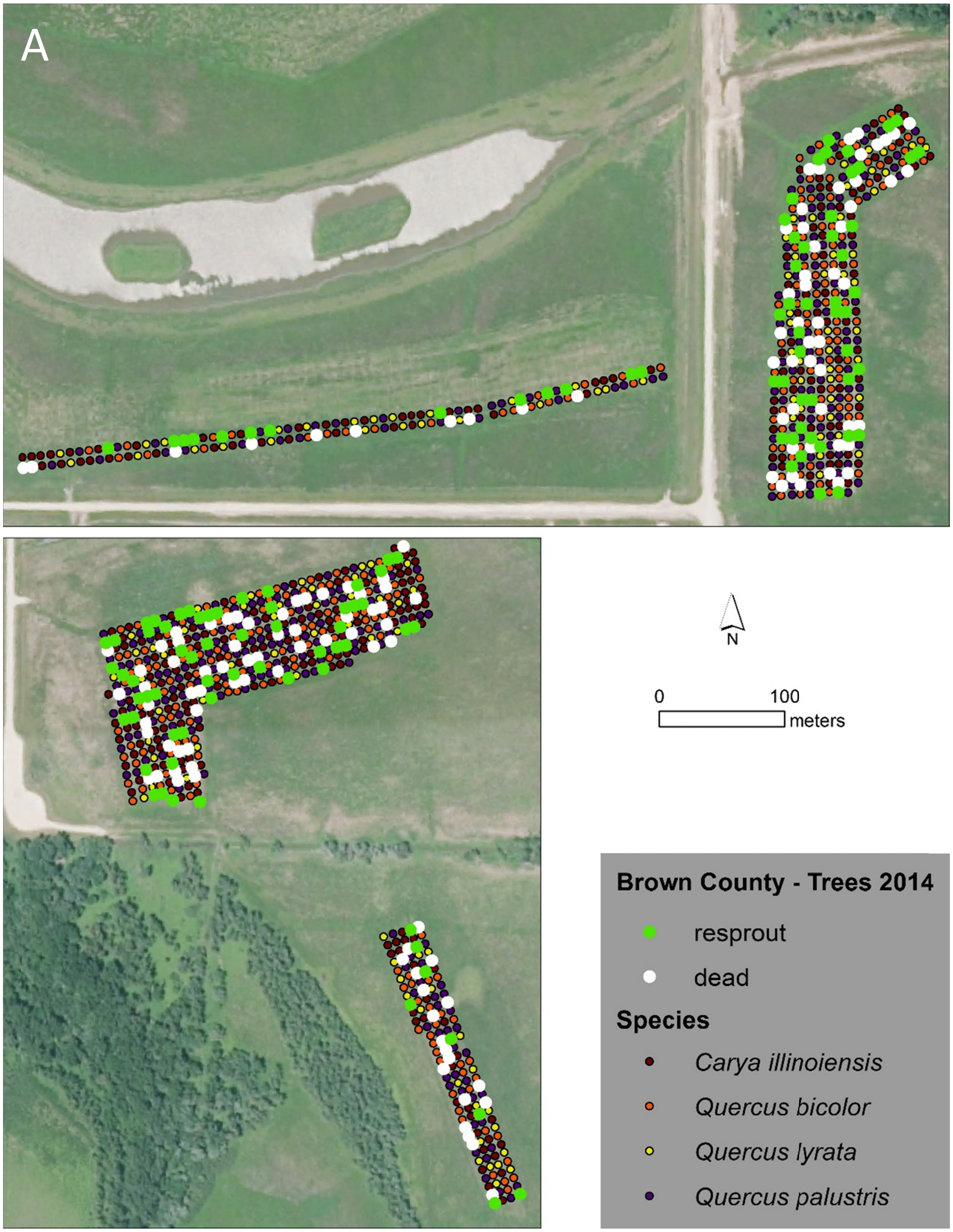

Figure 4a. Locations of planted trees surveyed at LaGrange Mitigation Bank, Brown County (A).

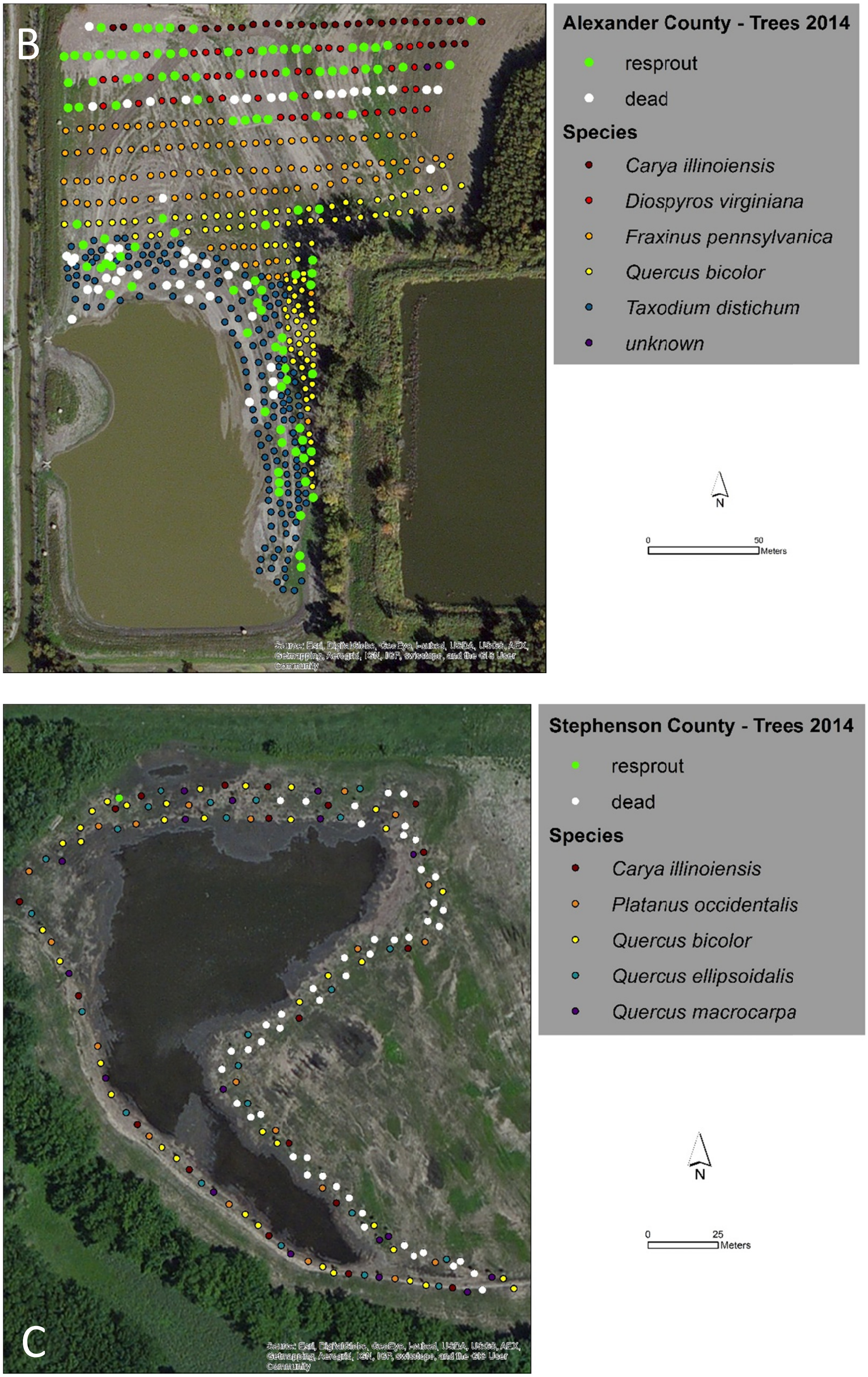

Figure 4b. Locations of planted trees surveyed at East Cape Girardeau site, Alexander County (B), and Weber site, Stephenson County (C).

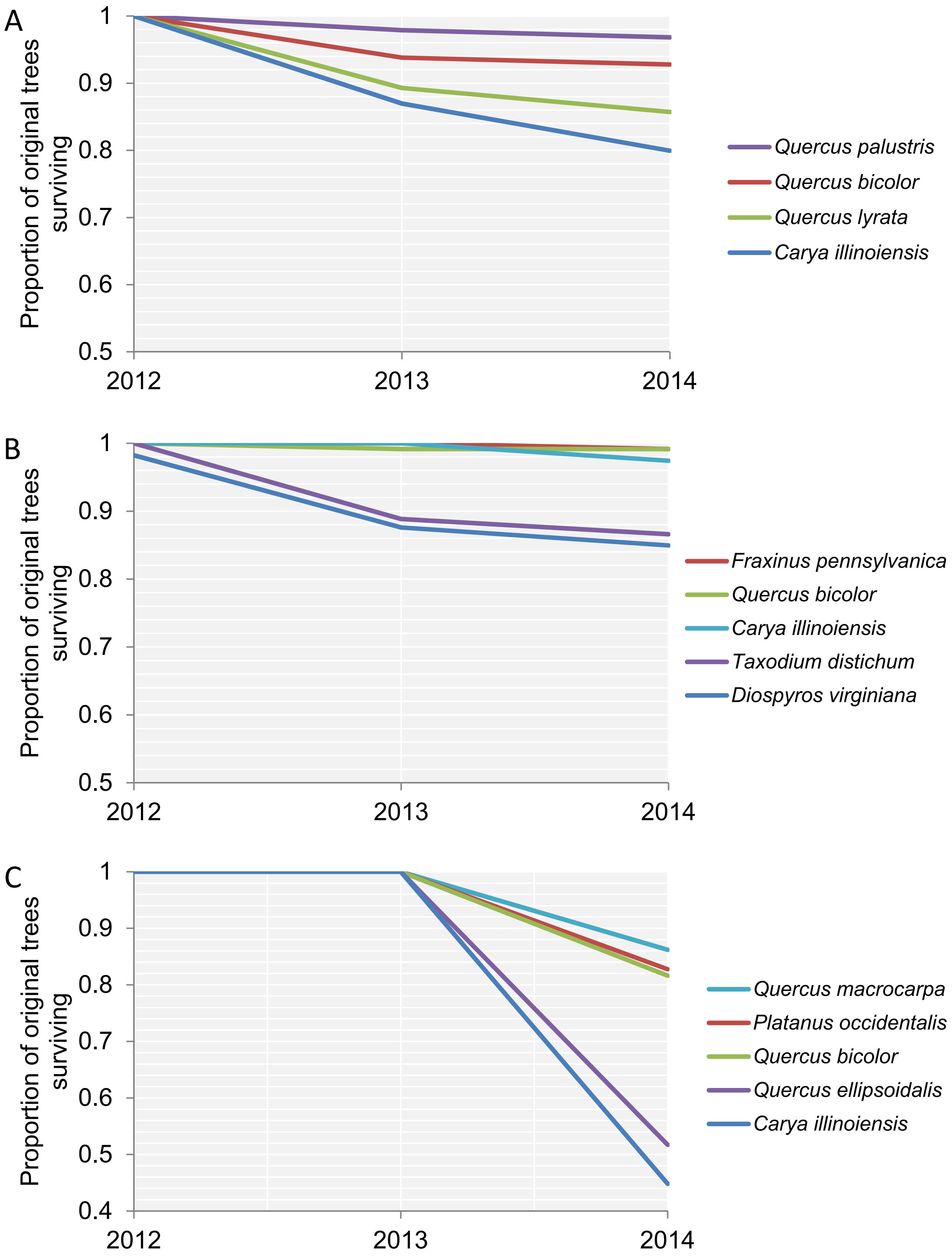

Figure 5. Trends in planted tree survival over 3 years in recently established mitigation wetlands at LaGrange Mitigation Bank, Brown County (A), East Cape Girardeau site, Alexander County (B), and Weber site, Stephenson County (C).

4.3 EFFECTS OF HYDROLOGIC REGIMES ON LONG-TERM PLANTED TREE SURVIVAL

During the summer of 2014, we reevaluated planted tree survival at ten IDOT mitigation wetlands that were at least 10 years old. In all cases, tree survival declined, sometimes dramatically, between the end of the mitigation site monitoring period and 2014 (Figure 6). For example, monitoring at the Gulfport site in Henderson County ended in 2003. A levee breach on the Mississippi River in 2008 submerged the village of Gulfport and its surroundings, apparently killing all trees planted at the mitigation site.

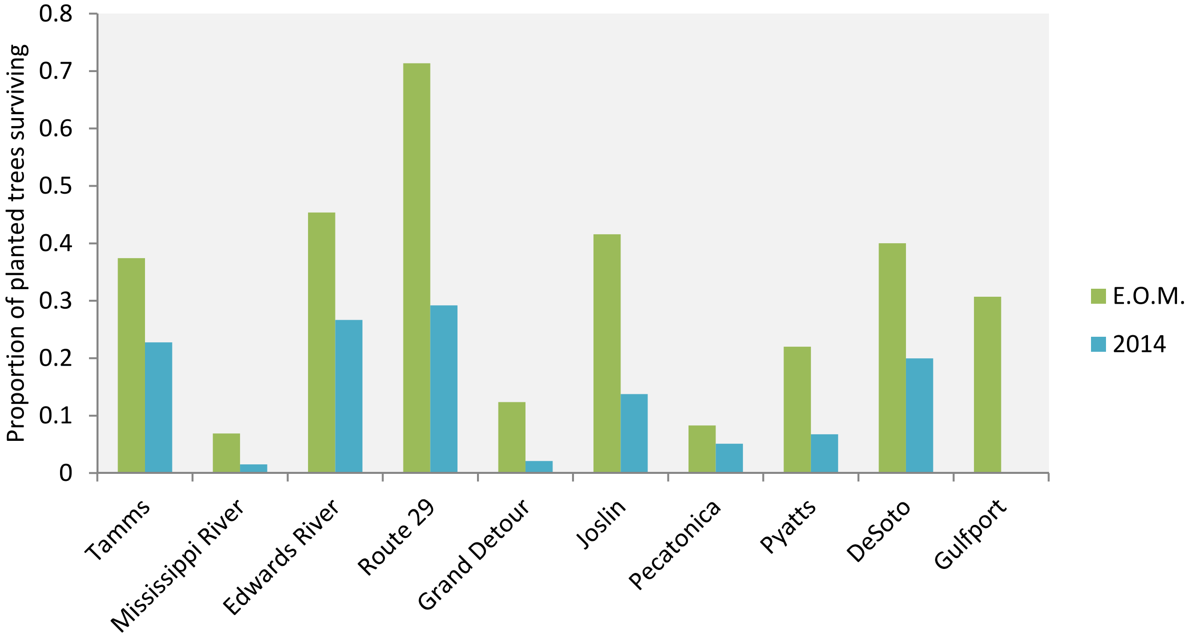

Figure 6. Proportion of all planted trees surviving (including replantings) in 10 mitigation wetlands at the end of site monitoring (E.O.M.) and in 2014.

Tree survival through 2014 decreased significantly as average maximum annual flood duration increased (Table 2). Tree survival also decreased significantly as average annual FEI_{max} increased (Table 2, Figure 7). Additionally, there was a marginally significant effect of average annual flood frequency on long-term tree survival.

Table 2. Results of Linear Regressions to Evaluate the Influence of Annual Flood Disturbance on Long-term Tree Survival and Volunteer Tree Recruitment

		flood frequency (number of events)		**maximum flood depth (m)**		**ln (maximum flood duration [days])**		**ln (FEImax [m.days])**	
Dependent variable	***n***	***F***	**parameter estimate**	***F***	**parameter estimate**	***F***	**parameter estimate**	***F***	**parameter estimate**
proportion of planted trees surviving in 2014	10	5.09	–0.119	0.92	–0.090	**11.63****	–0.138	**8.11***	–0.138
volunteer tree stem density	13	0.11	–24.52	0.35	–107.96	1.90	324.82	0.00	–0.103
volunteer tree basal area	13	0.14	0.711	0.16	1.353	**8.86***	10.41	1.50	0.247
volunteer tree species richness	13	0.56	0.157	0.03	–0.099	0.19	–0.317	0.36	–0.305

*$p < 0.05$, **$p < 0.01$

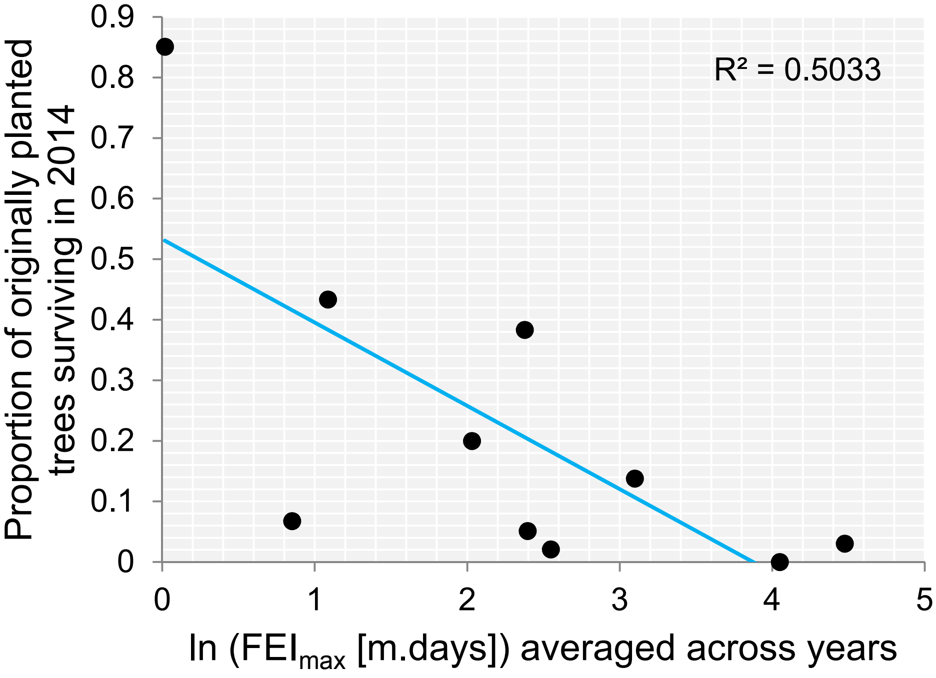

Figure 7. Proportion of originally planted trees surviving in mitigation wetlands in 2014 vs. log-transformed, average annual flood exposure index (FEI_{max}).

4.4 VOLUNTEER TREE RECRUITMENT IN MITIGATION WETLANDS

We assessed natural colonization by trees at 13 mitigation wetlands in 2014. Natural colonization greatly exceeded planting in terms of stem density, basal area, and number of species (Figures 8 and 9). However, species composition differed between naturally colonizing trees and planted trees (Figures 8 and 9). Natural colonization was dominated by wind-dispersed, early-colonizing species such as black willow (*Salix nigra*), silver maple, cottonwood, green ash, and sandbar willow (*Salix interior*). We observed no colonization by hard-mast species like oaks and hickories in the sampled plots. In contrast, oak species, along with river birch, were well-represented among planted species.

Somewhat surprisingly, stem density, basal area, and species richness of naturally colonizing trees were not clearly related to flood exposure (Table 2). Total basal area of naturally colonizing trees increased significantly as average maximum flood depth increased (Table 2). However, this effect was due entirely to a single outlier site with very high volunteer basal area and was no longer significant after the outlier was removed.

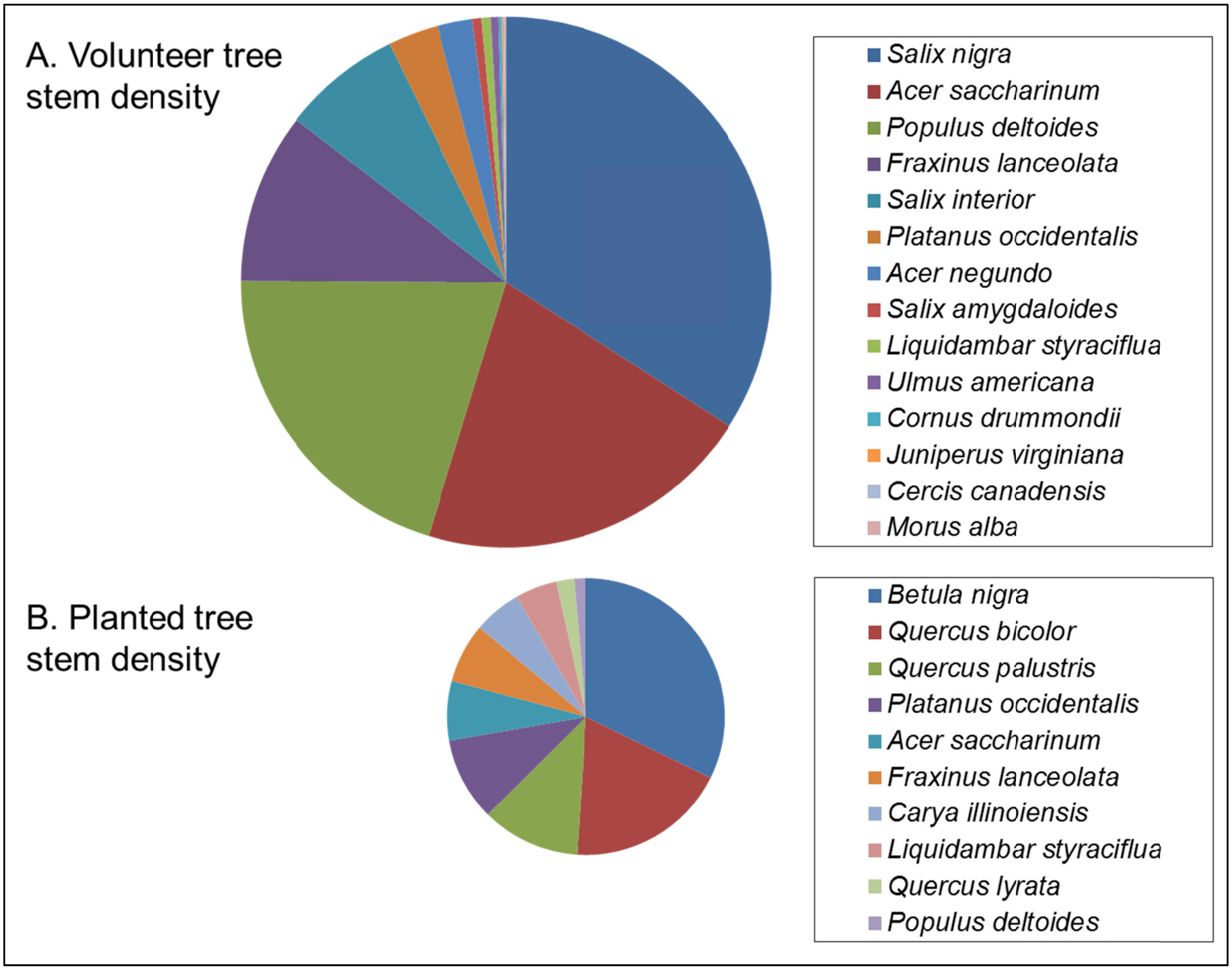

Figure 8. Relative stem density of volunteer and planted trees, by species, in 13 mitigation wetlands. Relative area of the two circles is scaled based on total stem density summed for all sites.

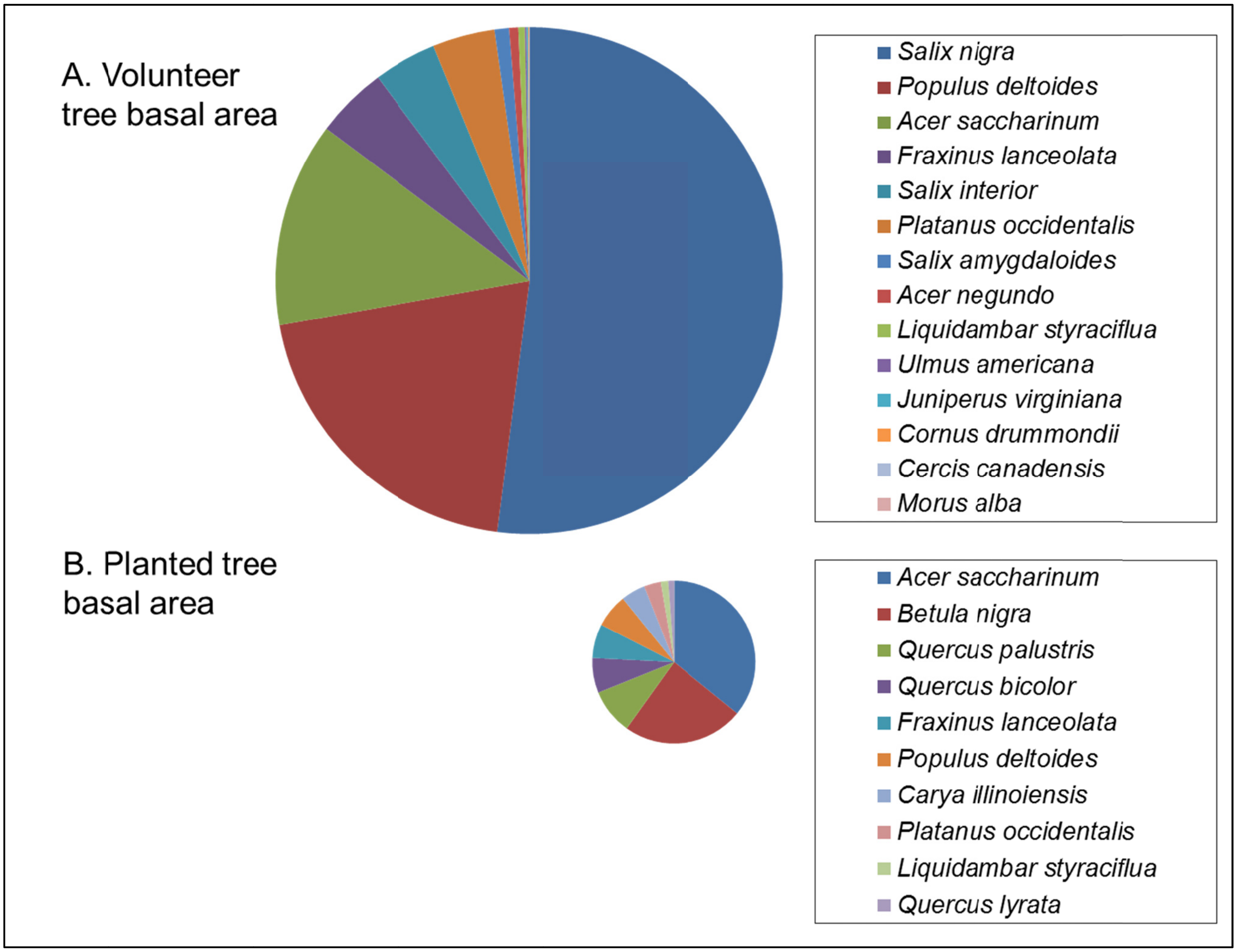

Figure 9. Relative basal area of volunteer and planted trees, by species, in 13 mitigation wetlands. Relative area of the two circles is scaled based on total basal area summed for all sites.

CHAPTER 5 CONCLUSIONS

Overall planted tree survival rate was low in compensatory mitigation wetlands, even after replanting. The number of planted trees alive at mitigation wetlands by the end of mitigation monitoring was, on average, 57% the number of trees planted originally. Survival rate continued to decline beyond site monitoring periods. Tree mortality was clearly related to site exposure to flood disturbance over the course of individual years, through the end of site monitoring, and beyond site monitoring periods. Flood exposure appears to impose a "ceiling factor" effect on planted tree survival; survival can be either high or low at sites with lesser flood exposure, but survival is invariably low at sites with greater flood exposure. Thus, other factors are likely important for determining tree survival in sites with lesser flood exposure. For example, the size and species of planted trees, as well as management and replanting efforts, varied among sites and may have influenced survival rates. Furthermore, factors such as herbivory and competition with naturally colonizing vegetation probably contributed to planted tree mortality.

Depth and duration of inundation were more important than flood frequency in determining tree survival. Most woody species are tolerant of brief flooding, but tissue damage accumulates with prolonged flooding and soil anoxia (Glenz et al. 2006). Deeper flooding is more stressful because deeper water prevents oxygen diffusion from the atmosphere and prevents the resupply of oxygen from leaves and lenticels to the roots (Hook 1984, Glenz et al. 2006). Thus, the combination of prolonged inundation of soils and deep inundation is particularly stressful for plants. The combined index, FEI_{max}, often explained more variation in tree survival than maximum depth or duration alone. Flood frequency and timing, although less important in this study, have been shown to be important in other studies (Glenz et al. 2006). With more frequent flooding, trees have a shorter recovery time between subsequent floods (Toner and Keddy 1997).

Based on observations at individual sites (e.g., Figures 4A and 4C), we had expected that pecan mortality would be particularly large. However, across all sites, mortality rates were similar across the five species investigated in this study. Kabrick et al. (2012), in an experimental planting study, found that pecan had high survival in response to flood treatments, but it suffered extensive stem dieback. Pin oak, bur oak (*Quercus macrocarpa*), and especially black walnut (*Juglans nigra*) were also sensitive to flooding treatments, whereas swamp white oak was found to be flood tolerant (Kabrick et al. 2012). Since species-specific flood tolerance seems to vary widely among studies and sites, it is difficult to define precise flood tolerance ratings or planting recommendations. However, broadly defined tolerance ratings have been developed and may serve as a guide for planting trees in compensatory mitigation wetlands (Table 3).

Planting appropriate species in appropriate locations is critical for successful reforestation. We recommend monitoring hydrology and analyzing existing stage data, if available, at proposed mitigation sites prior to tree planting in order to identify appropriate planting locations within and among sites. In situations in which long-term hydrologic monitoring is impractical, other techniques might be used to identify appropriate planting locations. For example, soil magnetic susceptibility is a proxy for soil drainage, and might be useful as a quantitative predictor of planted tree survival and growth during restoration planning (Grimley et al. 2008). In addition to identifying appropriate planting locations, proper restoration management can reduce tree mortality. Larger individuals are less susceptible to flood stress, so investing in larger trees at the outset of restoration may improve success (Lin et al. 2004, Stanturf et al. 2004). Similarly, tall herbaceous plants such as giant ragweed (*Ambrosia trifida*) should be controlled to eliminate competition and shading, which allows planted trees to grow fast enough to escape some flood risk (Hall and Harcombe 1998, Stanturf et al. 2004).

Table 3. Flood Tolerance Ratings (adapted from Hook 1984)
for Woody Species Observed in IDOT Mitigation Sites

Waterlogging tolerance	**Species**
Most tolerant	*Cephalanthus occidentalis, Forestiera acuminata, Salix nigra, Taxodium distichum*
Highly tolerant	*Quercus lyrata*
Moderately tolerant	*Acer negundo, Acer rubrum, Acer saccharinum, Betula nigra, Diospyros virginiana, Fraxinus pennsylvanica, Gleditsia triacanthos, Ilex decidua, Liquidambar styraciflua, Platanus occidentalis, Populus deltoides, Quercus palustris, Ulmus americana*
Weakly tolerant	*Carya illinoiensis, Celtis laevigata, Celtis occidentalis, Juglans nigra, Quercus shumardii*
Least tolerant	*Asimina triloba, Juniperus virginiana, Prunus serotina, Ulmus rubra*

Regulatory agencies often require the planting of hard-mast producing tree species in mitigation wetlands. Hard-mast tree species provide valuable food resources for wildlife, making these trees a priority for floodplain forest restoration (Shear et al. 1996). Heavy-seeded species like oaks and hickories may face dispersal limitation. Compared with species that produce numerous wind-dispersed seeds, hard-mast species do not readily colonize restorations or naturally regenerating forest stands (Shear et al. 1996, Battaglia et al. 2008, Yin et al. 2009). Our data on natural colonization in mitigation wetlands are consistent with this pattern. However, given the poor survival of hard-mast species observed in this and other studies and the clear relationship between flooding and planted tree mortality, it is unrealistic to expect that species such as oaks and pecans can be successfully established at all mitigation wetlands. Typical tree survival performance standards may be unachievable at many mitigation wetlands (Matthews and Endress 2008), particularly given the conflicting demands for restoring sites that are wet enough to meet jurisdictional wetland criteria over the entire site while simultaneously supporting floristically diverse, high-quality plant communities. Performance standards are unlikely to be achieved by continually replanting hard-mast species in locations where previously planted trees have died due to prolonged flooding.

Planting fast-growing species such as cottonwoods and silver maples does provide some benefits for ecological restoration. First, even these species will not readily colonize reforestation sites unless nearby seed sources are available, so planting can increase overall tree diversity (Allen 1997). Second, fast-growing species speed the development of vertical forest structure, providing wildlife habitat, including habitat for nesting birds (Twedt et al. 2002). Third, rapid canopy closure and the development of a shaded understory may prevent the establishment of aggressive, invasive plants such as reed canarygrass (*Phalaris arundinacea*). We are currently investigating inhibition of reed canarygrass by planted silver maples at an IDOT mitigation wetland in Henry County, Illinois. It should also be recognized that natural tree colonization can supplement planting, even in sites with extreme flooding where planted hard-mast species are unlikely to persist.

Most important, mitigation performance standards must be realistically attainable given likely hydrologic conditions at a site. Data from this research suggest that not all restoration goals are achievable at every site. There is a critical need for baseline information on the relationship between hydrology and vegetation communities in natural reference wetlands. Such baseline information could be used to set more realistic performance standards for mitigation wetlands.

REFERENCES

Acker, S.A., S.V. Gregory, G. Lienkaemper, W.A. McKee, F.J. Swanson, and S.D. Miller. 2003. "Composition, Complexity, and Tree Mortality in Riparian Forests in the Central Western Cascades of Oregon." *Forest Ecology and Management* 173:293–308.

Ahmad, Q.K., and A.U. Ahmed. 2003. "Regional Cooperation in Flood Management in the Ganges–Brahmaputra–Meghna Region: Bangladesh Perspective." *Natural Hazards* 28:181–198.

Allen, J.A. 1997. "Reforestation of Bottomland Hardwoods and the Issue of Woody Species Diversity." *Restoration Ecology* 5:125–134.

Andersson, E., C. Nilsson, and M.E. Johansson. 2000. "Plant Dispersal in Boreal Rivers and Its Relation to the Diversity of Riparian Flora." *Journal of Biogeography* 27:1095–1106.

Battaglia, L.L., S.A. Foré, and R.R. Sharitz. 2000. "Seedling Emergence, Survival and Size in Relation to Light and Water Availability in Two Bottomland Hardwood Species." *Journal of Ecology* 88:1041–1050.

Battaglia, L.L., P.R. Minchin, and D.W. Pritchett. 2002. "Sixteen Years of Old-field Succession and Reestablishment of a Bottomland Hardwood Forest in the Lower Mississippi Alluvial Valley." *Wetlands* 22:1–17.

Battaglia, L.L., D.W. Pritchett, and P.R. Minchin. 2008. "Evaluating Dispersal Limitation in Passive Bottomland Forest Restoration." *Restoration Ecology* 16:417–424.

Bendix J. 1997. "Flood Disturbance and the Distribution of Riparian Species Diversity." *Geographical Review* 87:468–483.

Bendix, J. 1999. "Stream Power Influence on Southern Californian Riparian Vegetation." *Journal of Vegetation Science* 10:243–252.

Bendix, J., and C.R. Hupp. 2000. "Hydrological and Geomorphological Impacts on Riparian Plant Communities." *Hydrological Processes* 14:2977–2990.

Breaux, A., and F. Serefiddin. 1999. "Validity of Performance Criteria and a Tentative Model for Regulatory Use in Compensatory Wetland Mitigation Permitting." *Environmental Management* 24:327–336.

Broadfoot, W.M., and H.L. Williston. 1973. "Flooding Effects on Southern Forests." *Journal of Forestry* 71:584–587.

Brown, P.H., and C.L. Lant. 1999. "The Effect of Wetland Mitigation Banking on the Achievement of No-net-loss." *Environmental Management* 23:333–345.

Brown, S.C., and P.L.M. Veneman. 2001. "Effectiveness of Compensatory Wetland Mitigation in Massachusetts, USA." *Wetlands* 21:508–518.

Cole, C.A. 2002. "The Assessment of Herbaceous Plant Cover in Wetlands as an Indicator of Function." *Ecological Indicators* 2:287–293.

Conner, W.H., I. Mihalia, and J. Wolfe. 2002. "Tree Community Structure and Changes from 1987 to 1999 in Three Louisiana and Three South Carolina Forested Wetlands." *Wetlands* 22:58–70.

Cronk, J.K., and M.S. Fennessy. 2001. *Wetland Plants: Biology and Ecology*. Boca Raton, FL: Lewis Publishers.

Dahl, T.E. 2000. *Status and Trends of Wetlands in the Conterminous United States 1986 to 1997*. Washington, DC: U.S. Fish and Wildlife Service, Department of Interior.

Damasceno-Junior, G.A., J. Semir, dos Santos, F.A.M., and H.F. Leitão-Filho. 2004. "Tree Mortality in a Riparian Forest at Rio Paraguai, Pantanal, Brazil, after an Extreme Flooding." *Acta Botanica Brasilica* 18:839–846.

De Jager, N.R., M. Thomsen, and Y. Yin. 2012. "Threshold Effects of Flood Duration on the Vegetation and Soils of the Upper Mississippi River Floodplain, USA." *Forest Ecology and Management* 270:135–146.

Environmental Law Institute (ELI). 2004. *Measuring Mitigation: A Review of the Science for Compensatory Mitigation Performance Standards*. Washington, DC: Environmental Law Institute. 271 pp.

Ernst, K.A., and J.R. Brooks. 2003. "Prolonged Flooding Decreased Stem Density, Tree Size and Shifted Composition Towards Clonal Species in a Central Florida Hardwood Swamp*." Forest Ecology and Management* 173:261–279.

Federal Register. 2008. Compensatory Mitigation for Losses of Aquatic Resources; Final Rule. Federal Register 73(70):19594–19705.

Glenz, C., R. Schlaepfer, I. Iorgulescu, and F. Kienast. 2006. "Flooding Tolerance of Central European Tree and Shrub Species." *Forest Ecology and Management* 235:1–13.

Grimley, D.A., J.S. Wang, D.A. Liebert, and J.O. Dawson. 2008. "Soil Magnetic Susceptibility: A Quantitative Proxy of Soil Drainage for Use in Ecological Restoration." *Restoration Ecology* 16:657–667.

Hall, R.B.W., and P.A. Harcombe. 1998. "Flooding Alters Apparent Position of Floodplain Saplings on a Light Gradient." *Ecology* 79:847–855.

Hook, D.D. 1984. "Waterlogging Tolerance of Lowland Tree Species of the South." *Southern Journal of Applied Forestry* 8:136–149.

Hough, P., and M. Robertson. 2009. "Mitigation under Section 404 of the Clean Water Act: Where It Comes From, What It Means." *Wetlands Ecology and Management* 17:15–33.

Howard, J.J. 2012. "Hurricane Katrina Impact on a Leveed Bottomland Hardwood Forest in Louisiana." *American Midland Naturalist* 168:56–69.

Hughes, F.M.R., W.M. Adams, E. Muller, C. Nilsson, K.S. Richards, N. Barsoum, H. Decamps, R. Foussadier, J. Girel, H. Guilloy, A. Hayes, M. Johansson, L. Lambs, G. Patou, J.-L. Peiry, M. Perrow, F. Vautier, and M. Winfield. 2001. "The Importance of Different Scale Processes for the Restoration of Floodplain Woodlands." *Regulated Rivers: Research & Management* 17:325–345.

Jarman, N.M., R.A. Dobberteen, B. Windmiller, and P.R. Lelito. 1991. "Evaluation of Created Freshwater Wetlands in Massachusetts." *Restoration and Management Notes* 9:26–29.

Kabrick, J.M., D.C. Dey, J.W. Van Sambeek, M.V. Coggeshall, and D.F. Jacobs. 2012. "Quantifying Flooding Effects on Hardwood Seedling Survival and Growth for Bottomland Restoration." *New Forests* 43:695–710.

Keddy, P.A. 2010. *Wetland Ecology: Principles and Conservation*, 2nd edition. Cambridge, UK: Cambridge University Press. 487 pp.

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

Kozlowski, T.T. 2002. "Physiological-ecological Impacts of Flooding on Riparian Forest Ecosystems." *Wetlands* 22:550–561.

Leyer, I. 2006. "Dispersal, Diversity and Distribution Patterns in Pioneer Vegetation: The Role of River–Floodplain Connectivity." *Journal of Vegetation Science* 17:407–416.

Lin, J., P.A. Harcombe, M.R. Fulton, and R.W. Hall. 2004. “Sapling Growth and Survivorship as Affected by Light and Flooding in a River Floodplain Forest of Southeast Texas.” *Oecologia* 139:399–407.

Loučková, B. 2012. “Vegetation-landform Assemblages Along Selected Rivers in the Czech Republic, a Decade After a 500-year Flood Event.” *River Research and Applications* 28:1275–1288.

Martin, S., R. Brumbaugh, and P. Hough. 2005. “Conceptualizing Mitigation Performance Standards.” *National Wetlands Newsletter* March–April:7–10.

Matthews J.W., and A.G. Endress. 2008. “Performance Criteria, Compliance Success, and Vegetation Development in Compensatory Mitigation Wetlands.” *Environmental Management* 41:130–141.

Middleton, B. 2000. “Hydrochory, Seed Banks, and Regeneration Dynamics Along the Landscape Boundaries of a Forested Wetland.” *Plant Ecology* 146:169–184.

Middleton, B.A. 2003. “Soil Seed Banks and the Potential Restoration of Forested Wetlands After Farming.” *Journal of Applied Ecology* 40:1025–1034.

Mitsch, W.J., and J.G. Gosselink. 2007. *Wetlands*, 4th edition. Hoboken, NJ: John Wiley & Sons.

Mitsch, W.J., and W.G. Rust. 1984. “Tree Growth Responses to Flooding in a Bottomland Forest in Northeastern Illinois.” *Forest Science* 30:499–510.

Morgan, K. L., and T.H. Roberts. 2003. “Characterization of Wetland Mitigation Projects in Tennessee, USA.” *Wetlands* 23:65–69.

Naiman, R.J., and H. Décamps. 1997. “The Ecology of Interfaces: Riparian Zones.” *Annual Review of Ecology and Systematics* 28:621–658.

National Research Council (NRC). 2001. *Compensating for Wetland Losses under the Clean Water Act*. Washington, DC: National Academy Press, 322 pp.

Nygaard, B., and R. Ejrnæs. 2009. “The Impact of Hydrology and Nutrients on Species Composition and Richness: Evidence from a Microcosm Experiment.” *Wetlands* 29:187–195.

Pennington, M.R., and M.B. Walters. 2006. “The Response of Planted Trees to Vegetation Zonation and Soil Redox Potential in Created Wetlands.” *Forest Ecology and Management* 233:1–10.

Pociask, G.E. and J.W. Matthews. 2013. *Restoration Progress and Flood Disturbance at IDOT Wetland Mitigation Sites*. Illinois Center for Transportation Series No. 13–016. Rantoul, IL: Illinois Center for Transportation.

Prach, K., and R.J. Hobbs. 2008. “Spontaneous Succession Versus Technical Reclamation in the Restoration of Disturbed Sites.” *Restoration Ecology* 16:363–366.

Richardson, D.M., P.M. Holmes, K.J. Esler, S.M. Galatowitsch, J.C. Stromberg, S.P. Kirkman, P. Pyšek, and R.J. Hobbs. 2007. “Riparian Vegetation: Degradation, Alien Plant Invasions, and Restoration Prospects.” *Diversity and Distributions* 13:126–139.

Richter B.D, J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. “A Method for Assessing Hydrologic Alteration Within Ecosystems.” *Conservation Biology* 10:1163–1174.

Shear, T.H., T.J. Lent, and S. Fraver. 1996. “Comparison of Restored and Mature Bottomland Hardwood Forests of Southwestern Kentucky.” *Restoration Ecology* 4:111–123.

Singer, J.D. 1998. “Using SAS PROC MIXED to Fit Multilevel Models, Hierarchical Models, and Individual Growth Models.” *Journal of Educational and Behavioral Statistics* 24: 323–355.

Sluis, W., and J. Tandarich. 2004. “Siltation and Hydrologic Regime Determine Composition in Herbaceous Floodplain Communities.” *Plant Ecology* 173:115–124.

Stanturf, J.A., W.H. Conner, E.S. Gardiner, C.J. Schweitzer, and A.W. Ezell. 2004. “Recognizing and Overcoming Difficult Site Conditions for Afforestation of Bottomland Hardwoods.” *Ecological Restoration* 22:183–193.

Streever, W.J. 1999. Examples of Performance Standards for Wetland Creation and Restoration in Section 404 Permits and an Approach to Developing Performance Standards. WRP Technical Notes Collection, TN WRP WG-RS-3.3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Suloway, L., and M. Hubbell. 1994. *Wetland Resources of Illinois: An Analysis and Atlas*. Champaign, IL: Illinois Natural History Survey, Special Publication 15. 88 pp.

Toner, M., and P. Keddy. 1997. “River Hydrology and Riparian Wetlands: A Predictive Model for Ecological Assembly.” *Ecological Applications* 7:236–246.

Turner, M.G., S.E. Gergel, M.E. Dixon, and J.R. Miller. 2004. “Distribution and Abundance of Trees in Floodplain Forests of the Wisconsin River: Environmental Influences at Different Scales.” *Journal of Vegetation Science* 15:729–738.

Twedt, D.J., R.R. Wilson, J.L. Henne-Kerr, and D.A. Grosshuesch. 2002. “Avian Response to Bottomland Reforestation: The First 10 Years.” *Restoration Ecology* 10:645–655.

United States Army Corps of Engineers (USACE). 2012. RiverGages.com: Water Levels of Rivers and Lakes. Available online at http://www2.mvr.usace.army.mil/WaterControl/new/layout.cfm.

United States Geological Survey (USGS). 2012. National Water Information System: Web Interface. Available online at http://waterdata.usgs.gov/il/nwis/rt.

Urban, D.T. 2008. “Rule Offers Philosophy Change to Mitigation.” *National Wetlands Newsletter* 30:5-7.

Wallace, P.M., D.M. Kent, and D.R. Rich. 1996. “Responses of Wetland Tree Species to Hydrology and Soils.” *Restoration Ecology* 4:33–41.

Walling, D.E., and A. Teed. 1971. “A Simple Pumping Sampler for Research into Suspended Sediment Transport in Small Catchments.” *Journal of Hydrology* 13:325–337.

Wilson, S.D., and P.A. Keddy. 1985. “Plant Zonation on a Shoreline Gradient: Physiological Response Curves of Component Species.” *Journal of Ecology* 73:851–860.

Yin, Y. 1998. “Flooding and Forest Succession in a Modified Stretch Along the Upper Mississippi River.” *Regulated Rivers: Research & Management* 14:217–225.

Yin, Y., Y. Wu, S.M. Bartell, and R. Cosgriff. 2009. “Patterns of Forest Succession and Impacts of Flood in the Upper Mississippi River Floodplain Ecosystem.” *Ecological Complexity* 6:463–472.

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