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RESTORATION PROGRESS AND FLOOD DISTURBANCE AT IDOT WETLAND MITIGATION SITES

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IDOT Wetland Mitigation Sites

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16. Abstract

As required under Section 404 of the Clean Water Act and the Illinois Interagency Wetland Policy Act of 1989, the Illinois Department of Transportation (IDOT) has established wetlands at mitigation sites throughout Illinois to compensate for impacts to natural wetlands by road construction. One of the mechanisms for meeting regulatory obligations is to mitigate wetland impacts through restoration or creation of wetlands that provide functions similar to natural wetlands, under the federal policy goal of “no net loss” of wetland area and function. Progress toward restoring wetland functions is measured through the use of prescribed performance standards issued by state and federal regulatory agencies. In most cases, these performance standards contain measures of quality, health, and structure of wetland plant communities.

The majority of extant Illinois wetlands and most IDOT wetland mitigation sites are located in floodplain areas and are exposed to varying degrees of flooding, depending on their location within a given watershed, their position within the floodplain setting, and their climate zone within the state. Among the major challenges in attaining vegetation-based performance standards at IDOT wetland mitigation projects are poor plant-community quality (e.g., low species richness) and mortality of planted trees. Although floodplain wetlands are supported by regular flooding, floods can also produce excessive sediment, cause ice damage, and result in prolonged inundation—leading to mortality in wetland plants, thereby interrupting expected trajectories of succession and progress toward achieving mitigation performance standards.

In this study, we analyzed data collected by the Illinois Natural History Survey and the Illinois State Geological Survey during past and current site monitoring to examine the influence that flooding has on ecological mechanisms that lead to variation in the performance levels among a large number of floodplain compensatory mitigation wetlands. The goals of the analyses were to evaluate the influence that flooding has on (1) plant-community quality at the landscape scale and (2) species turnover within plant-community functional groups at wetland mitigation sites. For the first component of the analysis, we used simple linear regression to evaluate the influence of flooding on the levels of ten plant-community metrics. Results of linear regression analysis showed significant, inverse relationships between mean annual flood exposure and average levels of three of the ten plant-community metrics: species richness, floristic quality index (FQI), and proportion of perennial species. Also, we used hierarchical mixed models to evaluate the influence of flooding on loss and subsequent gain of species within seven species functional groups. Mixed models showed significant correlation of the loss of species within all species groups with magnitude of flood intensity in the same year, and the gain of non-hydrophytic, annual, and non-native species with magnitude of flood intensity in the preceding year. Results of this study indicate two general tendencies at IDOT wetland mitigation sites: (1) Higher average magnitudes of flooding will lead to decreased species richness, floristic quality, and proportion of perennials in floodplain settings and significantly decrease the likelihood of attaining performance standards based on these metrics; and (2) higher-magnitude floods will tend to disrupt succession by eliminating the species groups that are associated with higher-quality plant communities and allow more undesirable species to colonize in the year following flood disturbance. These tendencies highlight the importance of considering flood-disturbance regime, when evaluating the quality of plant communities in floodplain wetlands.

Additionally, planted-tree counts and mapping were conducted to provide a baseline for future tree-survival studies at three sites. Potential future studies would track survivorship of each tree species in response to flood disturbance.

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EXECUTIVE SUMMARY

As required under Section 404 of the Clean Water Act and the Illinois Interagency Wetland Policy Act of 1989, the Illinois Department of Transportation (IDOT) has established wetlands at mitigation sites throughout Illinois to compensate for impacts to natural wetlands by road construction. One of the mechanisms for meeting regulatory obligations is to mitigate wetland impacts through restoration or creation of wetlands that provide functions similar to natural wetlands under the federal policy goal of "no net loss" of wetland area and function. Progress toward restoring wetland functions is measured through the use of prescribed performance standards issued by state and federal regulatory agencies. In most cases, these performance standards contain measures of quality, health, and structure of wetland plant communities.

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CONTENTS

CHAPTER 1 INTRODUCTION

Under Section 404 of the Clean Water Act (CWA) and the Illinois Interagency Wetland Policy Act of 1989 (IWPA), the Illinois Department of Transportation (IDOT) is often required to create or restore wetlands to mitigate the impacts to existing wetlands during construction projects permitted by the U.S. Army Corps of Engineers (USACE) and the Illinois Department of Natural Resources (IDNR). The underlying policy behind the CWA and the IWPA is no net loss of wetland area and function. The IDOT Bureau of Design and Environment administers a statewide wetlands program to coordinate compliance with these regulations.

Through this program, IDOT has developed numerous wetland mitigation sites throughout Illinois that encompass a variety of ecological and hydrogeological settings. However, most of the existing Illinois wetlands are located in floodplains (Suloway and Hubbell 1994). Therefore, road construction projects most often impact floodplain wetlands, and most IDOT wetland mitigation projects are located in floodplain settings. The locations of both impacts and mitigation projects span the range of watershed settings in Illinois—from small headwater streams to large rivers; thus, the flood regime varies widely among floodplain IDOT wetland mitigation sites. In qualitative terms, flood hydrology ranges from "flashy" in small headwater streams where flood stage peaks and recedes quickly, mainly in response to storm events, to "seasonal" flooding in large-river bottomlands where prolonged floods occur in response to regional, seasonal weather patterns in the river basin (Sparks et al. 1990). The variability of flooding along the floodplain from headwater floodplains along smaller streams to large-river bottomlands leads to downstream differentiation in wetland functions within a watershed (Brinson 1993).

The goal of wetland mitigation is to offset losses of wetland area and function by restoring or creating wetlands that provide functions similar to natural wetlands. Mitigation approaches for floodplain wetland mitigation projects typically include restoring wetland hydrology in drained or leveed areas that were formerly wetlands and/or creating wetland hydrology through excavation and/or impounding water in areas that were not formerly wetlands. In either case, the aim is to increase the duration of inundation and saturation to produce wetland hydrology (see section 1.1). Further, mitigation activities also include planting native species of herbs, shrubs, and trees and allowing varying degrees of natural regeneration of plant communities. After mitigation activities are complete, regulatory compliance for these projects includes monitoring whether jurisdictional wetlands have been established according to the three-parameter (i.e., wetland hydrology, hydric soils, and hydrophytic vegetation) definition of a wetland as outlined in the 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987), and evaluating whether wetlands provide functions similar to natural wetlands. In the case of wetland mitigation required under the CWA, progress toward restoring or creating wetland functions is measured through the use of performance standards (Streever 1999; *Federal Register* 2008). Among the major challenges in attaining vegetation performance standards at IDOT wetland mitigation projects are poor plant-community quality (e.g., low species richness, low proportions of perennial and native species) and mortality of planted trees. Moreover, wetland mitigation in floodplain areas can be particularly challenging because floods and associated processes (e.g., sedimentation, ice movement) can disrupt succession of plant communities, as well as damage or kill tree plantings (Figure 1).

Figure 1. Photos of inundation, sedimentation, and ice damage due to flooding of wetland mitigation projects. Photos show (a) inundation and ice formation around newly planted trees, (b) ice damage to trees after year 3 of restoration, (c) an early-growing-season flood that did not inundate most trees but killed plants in the herb layer, and (d) a late-season flood that coated plants and trees with sediment.

Despite the recognition that hydrology is a major factor contributing to the structure and function of wetlands, the degree of influence that hydrology has on wetland plant communities in particular settings is not well understood (Zedler 2000). Although understanding the interrelationship between the character of wetland plant communities and hydrology is critical to informing the management of wetlands, studies have only recently begun to focus on the link between hydrology and plant ecology (see Baird 1999; Asbjornsen et al. 2011). The goal of this study is to contribute to this emerging research theme, with the purpose of evaluating the role of flood disturbance in the progress of wetland restoration and creation sites. The benefit of this research is to provide a hydrologic context for assessing the progress of plant-community development that can inform decision making regarding wetland mitigation planning and adaptive management.

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 mitigation 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 three main components: (1) compiling flood statistics and quantifying flood characteristics, (2) evaluating the relationship between flooding and plant-community development with particular focus on vegetation-based performance metrics and the ecological mechanisms controlling their trajectories, and (3) establishing a baseline for determining the effect of flooding on planted-tree survival at newly constructed IDOT mitigation wetlands. The analysis of the response of plant communities to flooding consists of two components. For the first component of the analysis, we evaluate the influence of flooding on species gain and loss within seven species functional groups. For the second component of the analysis, the correlation in the levels of ten plant-community metrics with flooding is assessed. Further, progress in wetland establishment at selected IDOT wetland mitigation sites will be assessed in the context of the 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) and the 2010 *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Midwest Region* (USACE 2010a) to evaluate the consequences of recent changes in wetland delineation methodology.

CHAPTER 2 LITERATURE REVIEW

2.1 WETLAND CRITERIA AND PERFORMANCE STANDARDS

Since the 1970s, the recognition of the values, functions, and services that wetlands provide has led to the development of regulatory protections under Section 404 of the CWA, as well as state and local regulations (National Research Council 2001). Enforcement of these regulations often requires that wetlands be preserved, enhanced, restored, or created to offset impacts to wetlands during development activities. Wetland mitigation is intended to replace wetlands that are lost as a result of those impacts under the current national policy of "no net loss" of wetland area and function *(Federal Register* 2008). Therefore, performance standards are set as targets to allow regulators to evaluate whether mitigation projects are meeting objectives (Streever 1999; *Federal Register* 2008). To improve the wetland compensation process, the U.S. Environmental Protection Agency (USEPA) and the USACE recently issued updated rules for wetland compensation that clarify the use of ecological performance standards following from recommendations from the National Research Council (2001). 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 whether a compensatory mitigation project meets its objectives." *(Federal Register* 2008, p. 19672). Additionally, the Final Rule outlines other principles for ecological performance standards specifying that they need to be objective and verifiable, to be based on best available science, and *to 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).

After wetlands are created or restored under the IDOT Wetland Program, the USACE and the IDNR require monitoring to determine (1) if jurisdictional wetland area has been restored or created and (2) if the wetlands that are created are functioning at an acceptable level. The determination of jurisdictional wetland area uses criteria based on a three-parameter approach that requires the presence of (1) wetland hydrology, (2) hydric soils, and (3) hydrophytic vegetation and are outlined in the 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) or the applicable regional supplements (USACE 2010a, 2010b, 2012a). (See Table 1 of this report.)

Performance standards, most often based on vegetation characteristics, are set to determine whether a mitigation wetland is functioning at an acceptable level relative to natural wetlands. Examples of performance standards that have been issued for IDOT wetland mitigation projects are given in Appendix A. In general, each set of performance standards requires that wetland mitigation projects be dominated by native, non-weedy, perennial plant species and requires that sites achieve a minimum floristic quality index (FQI). Additionally, if restoring or creating forested wetlands is the objective of the mitigation project, performance standards regarding tree species and survival are issued by the USACE and IDNR.

Table 1. Comparison of jurisdictional wetland criteria outlined in the 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) and the *Midwest Regional Supplement* (USACE 2010a).

Parameter	1987 Manual	Midwest Regional Supplement
Hydrology (inundation or saturation)	5% or more during the growing season (median first and last occurrence 28°F air temperature), 12.5% in problematic situations	14 consecutive days during the growing season, based on the onset of biological activity (i.e., plant growth) or 41°F soil temperature at 12 in.
Soils	Occurrence of hydric soils or conditions that support hydric soil formation	Occurrence of hydric soils or conditions that support hydric soil formation
Vegetation	More than 50% of the dominant plant species must be hydrophytic at each sampling location.	Rapid test, dominance test, prevalence index, or morphological adaptations criteria must be satisfied.

2.2 FLOOD DISTURBANCE AND PLANT COMMUNITIES AT THE LANDSCAPE SCALE

Flood disturbance can have a strong influence on the structure of plant communities (e.g., Bornette and Amoros 1996; Bendix 1997; Toner and Keddy 1997; Pollack et al. 1998) and therefore is an important factor to consider in the progress of wetland plant-community establishment at migration sites. The intermediate disturbance hypothesis, the proposition that species richness is highest in places where disturbance occurs at moderate intensities or frequencies (Connell 1978; Bendix 1997) (Figure 2), provides a general framework for discussing the relationship of flood disturbance to plant-community response at the landscape scale. In the case of flood disturbance and plant communities, flood disturbances impact some portion of the plant community, depending on flood intensity or frequency. More intense or frequent floods cause more mortality in the plant community; and subsequently, relatively few species will initially colonize areas made available by flood disturbance. Therefore, in areas with high disturbance frequencies or magnitudes, the plant community will be composed of those few species. Where flood disturbances are rare or of low magnitude, relatively few species with competitive advantages suited to the available resources and resistant to other types of disturbance (e.g., drought, invasive species) dominate the plant community, leading to low species diversity. In contrast to these two extremes, higher species diversity occur in areas that have moderate intensities or frequencies of flood disturbance, as some portion of the plant community withstands disturbance while additional species replace those that are eliminated by disturbances. However, more recent studies have found that the distribution of species richness along a disturbance gradient does not always follow the peaked, parabolic distribution as suggested by the intermediate disturbance hypothesis and that a variety of shapes can describe the relationship between species diversity and disturbance (Mackey and Currie 2001; Hughes et al. 2007). Therefore, it is important to evaluate the distribution of species diversity and other aspects of the plant community along a disturbance gradient to discern the relative influence of flood disturbance versus other factors that could potentially influence performance of wetland mitigation sites.

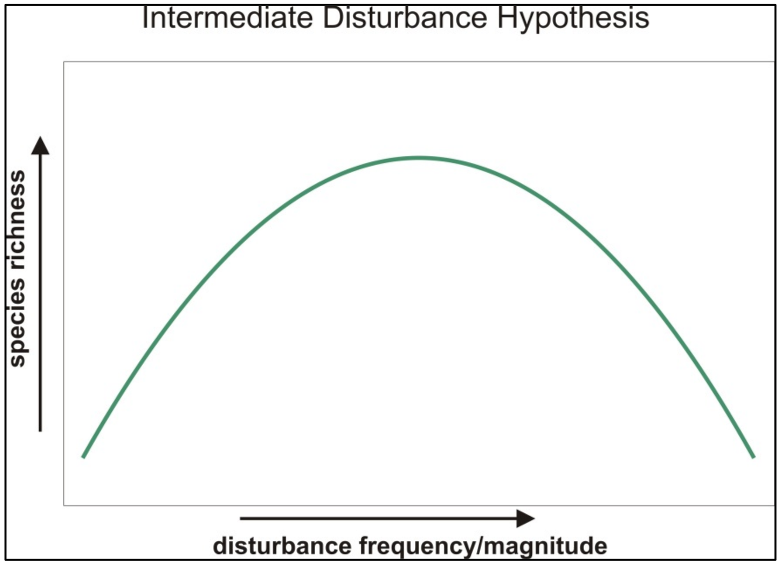


Figure 2. Graph illustrating the intermediate disturbance hypothesis
(after Connell 1978; see also Bendix 1997).

2.3 SUCCESSIONAL TRAJECTORIES IN MITIGATION WETLANDS

A common assumption that is reflected in performance standards is that wetland mitigation activities, along with varying degrees of self-design, facilitate a simple, steady trend toward a stable, natural state within a relatively short time (see Matthews et al. 2009a for discussion). Restoration progress within the plant community is often conceptualized as a developmental trajectory. Ideally, a given measurable indicator of restoration would increase as a wetland mitigation site ages until it reaches some pre-established goal (see "expected trajectory" in Figure 3). The concept is useful for comprehending how wetland restorations succeed or fail (Bradshaw 1984; Kentula et al. 1992; Aronson and Le Floc'h 1996). However, in settings with complex disturbance-response characteristics such as in floodplain wetlands, flood disturbance can lead to increased or decreased post-disturbance species diversity (Pollack et al. 1998). For example, occasional high-magnitude floods can kill all or portions of an established plant community where invasive or weedy species were once dominant, allowing other species to colonize and thereby increase biodiversity and community quality. By contrast, frequent high-magnitude flooding may prevent most perennials from becoming established and allow only a few weedy species to grow.

Species turnover rates, the balance between the addition of new species through planting and natural colonization versus the loss of existing species through local extinction, will determine the level of species diversity in a plant community. Matthews and Endress (2010) tracked changes in local colonization and extinction rates of plant species through succession in 24 IDOT mitigation wetlands. Results showed that, in general, new species colonized rapidly at first; but colonization rate declined through time. This change happens because opportunities for plant establishment and growth decrease over time as space and resources become occupied by early arriving plants. In contrast, annual rates of species extinction from sites did not change much over time; so by the fourth or fifth year after wetland mitigation activities were complete, although there was still turnover in species composition, the overall number of species stabilized in most sites (e.g., see "expected trajectory" in Figure 3). Despite this general pattern, succession trajectories can display a variety of shapes. In fact, close examination of changes in individual sites often reveals irregular successional trajectories that likely reflect the influence of a variety of ecological forcings.

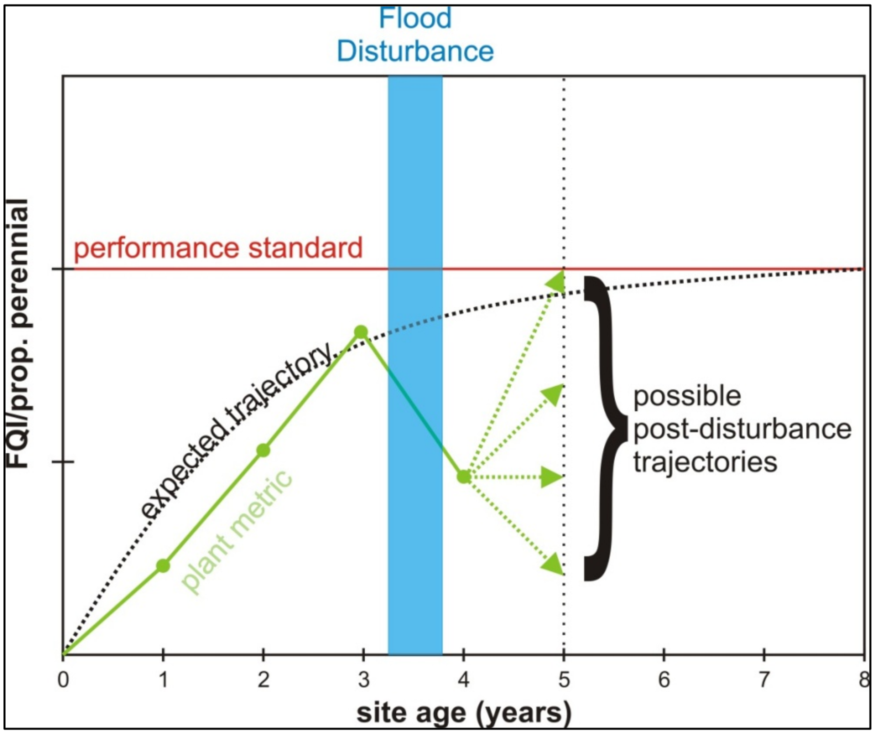


Figure 3. Schematic showing expected trajectory of succession without disturbance and possible post-disturbance trajectories of vegetation-based performance standards.

Previous work by Matthews et al. (2009a) described changes through time in 11 indicators of floristic integrity in 29 IDOT mitigation wetlands, including sites in floodplain settings. Floristic indicators based on species richness (including native richness, number of native genera, and floristic quality index [FQI]) rapidly increased asymptotically, exceeding levels in most natural reference wetlands. In contrast, indicators based on species composition, including mean coefficient of conservatism (mean *C*) and relative importance of perennial species, increased very slowly or followed no discernible pattern through time. Failure to follow expected asymptotic trajectories can be attributed in part to establishment and increasing dominance by non-native species (Matthews et al. 2009a; Matthews and Spyreas 2010). Other constraints to restoration progress include slow succession imposed by the inability of desired species to colonize the restored site (Galatowitsch 2006), constraints on the direction of successional trajectories resulting from large-scale landscape alteration (Simenstad et al. 2006), and external events such as floods and pathogen outbreaks (Simenstad and Thom 1996; Zedler and Callaway 1999). Thus, temporal variability in the form of disturbance events or long-term changes can lead to unexpected trajectories within various aspects of the plant community (Figure 3). Moreover, evaluating how particular ecological forcings, such as flood disturbance, influence this process is critical to understanding why a particular mitigation wetland is or is not meeting plant-community diversity goals.

2.4 EXAMPLE TRAJECTORIES FROM IDOT WETLAND MITIGATION SITES

Below, we provide data from several examples of individual wetland mitigation sites, based on previous work (Matthews and Pociask 2011) to illustrate successional trajectories at IDOT floodplain wetland mitigation projects in a variety of watershed settings. The first example illustrates a pronounced disturbance-recovery event in the plant community due to an extreme flood at a floodplain mitigation site along the Sangamon River in Sangamon County, Illinois (Figure 4). A major flood occurred in May 2002, the second growing season after mitigation activities (i.e., excavation of shallow basins and tree plantings) were completed. This flood event resulted in the loss of 46% of the plant species present in 2001, a decline in the relative proportion of perennial species, and a 25% mortality of planted trees. Many hydrophytic plant species were lost during the flood; but losses of upland species were more severe, leading to a decrease in mean wetland indicator status (WIS), marking a shift toward a “wetter” plant community. The rate of colonization by new species peaked in the year following the flood, allowing species richness to resume its pre-flood trajectory by 2003. This example illustrates (1) a marked influence of flood disturbance on the trajectory of plant-community development, (2) a subsequent recovery to pre-disturbance levels of species diversity, and (3) an increasing trajectory of species richness with site age under more moderate flood conditions (Matthews and Pociask 2011).

As mentioned previously, a variety of successional trajectories are possible and may often be irregular, not following steady, increasing trends (see Figure 2). This finding is further illustrated in the following examples taken from a variety of mitigation sites that span the range of watershed settings of IDOT wetland mitigation projects.

- *Example A: Headwaters.* Flooding at a headwater floodplain wetland mitigation site near Orangeville, Illinois, seldom exceeded a few days; and the graph below shows that floods had very little influence on the composition of the plant community (Figure 5A). The overall plant community was relatively diverse and appeared to be unaffected by the short-duration flooding that occurred at the site.
- *Examples B and C: Upper-middle reaches 1 and 2.* These sites are located in the Pecatonica River watershed in Stephenson and Winnebago Counties, respectively. Each showed a similar disturbance-response process to the first case example—substantial species loss in a year with relatively long duration of flooding and recovery of species richness in the following year (see Figures 4, 5B, and 5C). However, although both sites showed some recovery of plant species richness in the year following relatively intense flooding in 2008, the Reach 1 site showed a rebound of species richness to pre-disturbance levels and the Reach 2 site showed a recovery to a lower than pre-disturbance level in the year following the flood, despite the similar watershed setting.
- *Example D: Lower-middle reach.* This example, from a site in Henry County along the Rock River, showed a pattern of more regular flooding, which results in a relatively long total annual duration in most years (Figure 5D). This example contrasts with Examples B and C in that more regular recurrence of flooding is associated with a more monotonic, albeit slow, successional trajectory at relatively low levels of species richness.
- *Example E: Large-river bottomland.* This example, from a site along the Mississippi River in Alexander County, showed the highest-magnitude floods and high interannual variability. Unlike examples from smaller watersheds, the trajectory of species richness showed a relatively steady decline, with overall low species richness (Figure 5E).

These examples illustrate that floods can disrupt the successional trajectory of species richness and cause tree mortality, thereby affecting performance levels of wetland mitigation sites. Following a punctuated flood disturbance, plant-community quality may recover quickly to pre-disturbance levels, as in the initial example from Sangamon County, or may recover at some lower level, as in Example C, depending on the flood regime at the site and local and landscape factors (Matthews et al. 2009b). Alternatively, sites with more regular, higher-magnitude flooding may lead to lower levels of species richness and may not follow an increasing trajectory (see Example E).

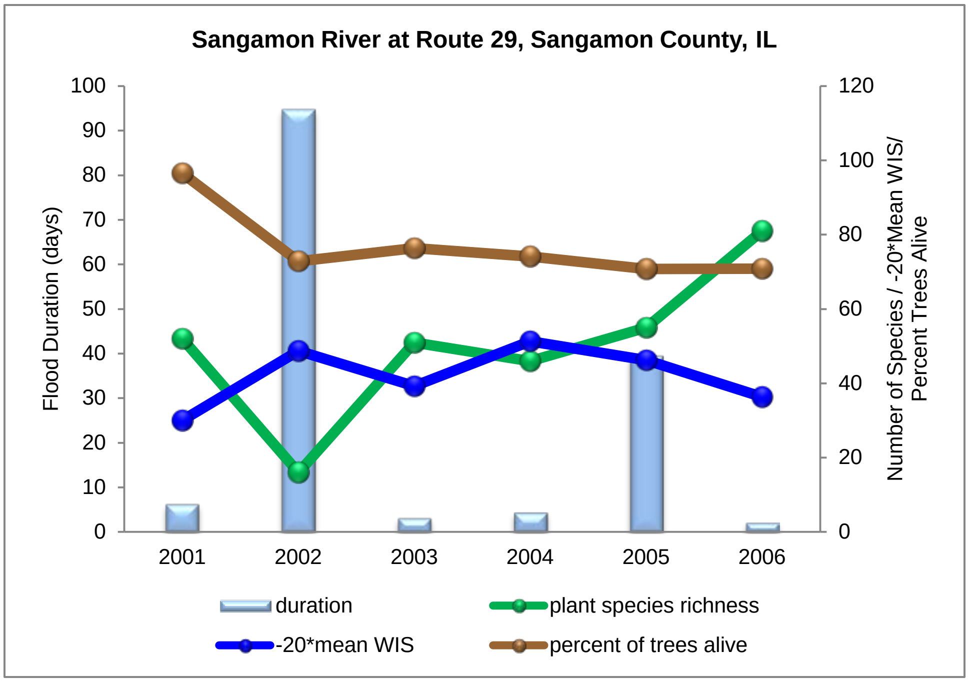


Figure 4. A case example from a wetland mitigation site, illustrating flood disturbance and plant-community recovery response. Note: In this figure, as well as Figure 5, wetland indicator status (WIS) is multiplied by a factor of –20 for display purposes.

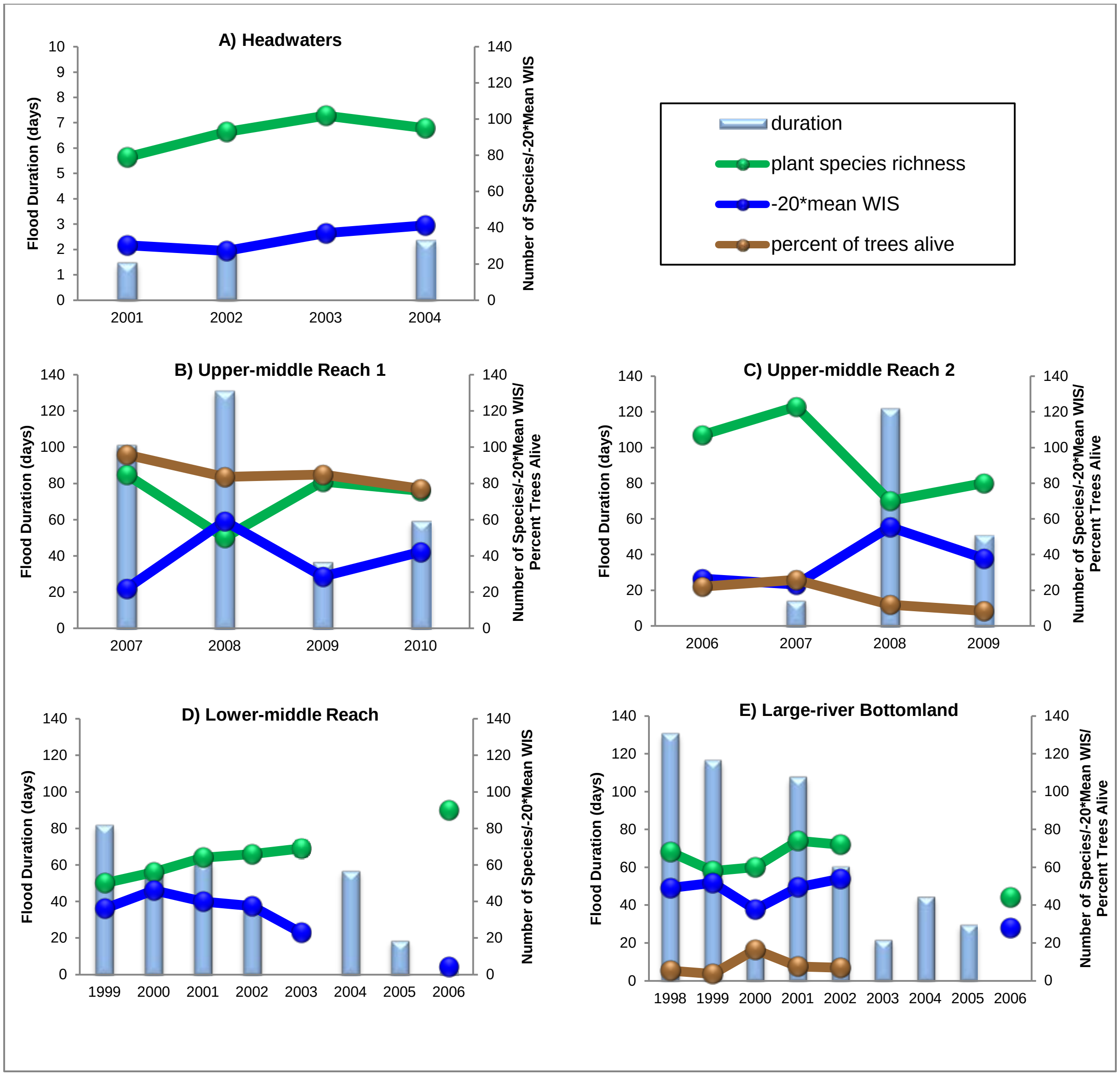


Figure 5. Case examples of sites with various flood regimes, providing a downstream view of flood disturbance and plant-community response at IDOT wetland mitigation sites. Each graph shows total annual flood duration (bars), plant-community species richness (green), and mean wetland indicator status (blue) for each year. Graphs B, C, and E also show percent of living trees (brown), relative to the initial planting (Matthews and Pociask 2011).

CHAPTER 3 METHODS

3.1 DATA ASSESSMENT AND SITE SCREENING

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 the site (1) is located within a floodplain and (2) receives direct flooding or has a hydrology that is influenced by the flood regime of the adjacent stream. Further, 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, 23 were selected (Figure 6). Sites were monitored between 1996 and 2011, and the overlapping duration of hydrologic and vegetation monitoring ranged from 3 to 8 years after initial wetland mitigation activities were completed. Contributing drainage areas for the selected sites ranged from 4 to ~1.8 million km^2, thus the sites represent a wide range of drainage area and correspondingly a wide range of flood regimes.

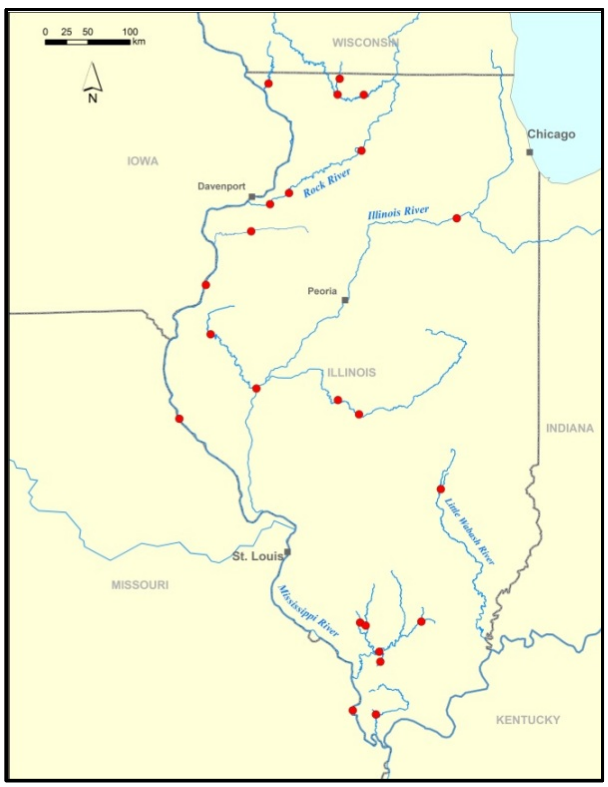


Figure 6. Map showing the locations of IDOT wetland mitigation sites used for the evaluation in this study.

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) (2012b) or the USACE (2012c). 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 to evaluate flood intensity for each flood event during the monitoring period at each site. Although 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 depth and duration of inundation of the wetland plant community. We used a 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

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

where D_{avg} is the average depth above a specified elevation threshold and R is the duration of the flood above a specified threshold elevation. The unit of flood exposure is meter-days. For the threshold elevation of each site, we selected a minimum site elevation at which the floodplain was inundated by river flooding 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. FEI was calculated for each flood event during each year of the monitoring period. We chose to use annual maximum FEI (FEI_{max}) as the independent variable for statistical analyses because this value represents the highest-magnitude flood in a given year and therefore represents the flood event that has the maximum effect on the plant community at a mitigation site. We also calculated the mean annual FEI_{max} over the monitoring period at each site to evaluate the average flood disturbance condition at each mitigation site.

3.3 VEGETATION SAMPLING AND PLANT-COMMUNITY METRICS

Vegetation at wetland sites was monitored annually, generally in late summer, which maximizes the number of identifiable plant species in wetlands. Sites selected for this study were monitored for at least 3 years, some for as many as 8 years, and included both forested and emergent wetlands.

A plant species list was compiled annually during a search of the entire site. In addition, in 15 of the 23 selected wetlands, vegetation was quantitatively sampled in square quadrats (1- or 0.25-m^2) placed systematically along transects. All vascular plant species observed in each quadrat were assigned a cover class (>1%, 1–5%, 6–25%, 26–50%, 51–75%, 76–95%, or 96–100%), and relative cover was calculated for each sampled species in each site.

For this study, we used annual vegetation monitoring data to calculate floristic indicators of wetland quality for each site in each year. These indicators are often used as performance standards for mitigation wetlands and included (1) total species richness, (2) mean *C*, (3) FQI, (4) mean WIS, (5) prevalence index (PI), (6) proportion of all species at the site that were hydrophytes, (7) proportion of all species at the site that were perennial, (8) summed cover of perennial species, (9) proportion of all species at the site that were native, and (10) summed cover of native species.

Indicators based on floristic quality (FQI and mean *C)* utilized coefficients of conservatism (*C*) assigned to each species in Illinois (Taft et al. 1997). Coefficients of conservatism are subjective ratings of species' relative fidelity to undegraded natural communities and range from 0 (weedy species) to 10 (conservative species, intolerant of habitat degradation). Mean *C* was calculated as the mean of coefficients of conservatism for all plant species at a site, and FQI was computed as

$$\mathbf{FQI} = \bar{C} \times \sqrt{S}$$

where *S* is the total number of plant species at the site (Swink and Wilhelm 1994).

Native status of species and species life spans (perennial vs. annual/biennial) were based on regional floras (Swink and Wilhelm 1994; Mohlenbrock 2002). Hydrophytic species were defined as facultative, facultative wetland, and obligate wetland species (Reed 1988). Mean WIS was calculated by assigning numerical values to each species and averaging across all species in a site. Prevalence index was calculated using species cover values following the 2010 *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Midwest Region* (USACE 2010a).

We calculated annual, proportional species gain (G_p) and loss (L_p) rates, based on species presence–absence data from each year, following Anderson (2007), as

$$G_p = \frac{G}{(0.5)(S_t + S_{t+1})}$$

$$L_p = \frac{L}{(0.5)(S_t + S_{t+1})}$$

where S_t is species richness in year *t*, *G* is the number of species observed in year *t*+1 not observed in year *t*, and *L* is the number of species observed in year *t* not observed in year *t*+1.

3.4 BASELINE TREE-SURVIVAL DATA COLLECTION

We initiated an experiment 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 +/- 0.5 m under optimal field conditions.

The locations of 1,912 planted trees were recorded: 165 trees at the Weber Site, 1,140 trees at the LaGrange Mitigation Bank, and 607 trees at the East Cape Girardeau site. 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 flood and drought events.

3.5 STATISTICAL ANALYSES

All statistical analyses were performed using SAS 9.3 statistical software (SAS Institute, Inc., Cary, North Carolina). We used simple linear regression to evaluate the effect of flood exposure on each of the ten plant-community metrics. We used FEI_{max} as the independent variable to quantify the maximum flood disturbance event in each year. Mean values for FEI_{max} and each of the plant metrics were calculated for the duration of monitoring for each site. Eleven linear regression analyses were performed: each of the ten plant metrics versus log-transformed FEI_{max}, and an analysis of plant species richness that accounted for the effect of site area. Further, analyses of plant species richness used natural log-transformed values.

We used hierarchical mixed models to evaluate the influence of flood disturbance, site age, and their combined interaction on the rates of annual species gain (colonization, G_p) and loss (extinction, L_p) from wetland mitigation sites. Hierarchical 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 sites. Site identity was included as a random factor in all models to account for underlying differences in gain and loss rates among sites. Plant species gain and loss rates were included as response variables in statistical models; and site age, FEI_{max}, and their two-way interaction were used as potential predictors. Initially, all plant species were included in the analyses. We then repeated the modeling process separately for six different categories of species (hydrophytes vs. non-hydrophytes, perennials vs. annuals, and natives vs. non-natives) to determine the effects of site age and flood exposure on different plant types. Full models were reduced using a backwards elimination procedure to eliminate non-significant ($p > 0.10$) predictor variables. Response variables (G_p and L_p) were log-transformed prior to analyses. A standard variance components covariance structure was selected.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 PLANT-COMMUNITY METRICS VS. FLOOD DISTURBANCE AT THE LANDSCAPE SCALE

IDOT wetland mitigation sites span the range of watershed settings in Illinois and correspondingly show a wide range of variability in calculated values of FEI_{max} (Table 2 and Figure 7). FEI values for maximum annual events during the monitoring period at each site ranged from 0.2 to 185.7 meter-days, and maximum annual cumulative values ranged from 0.2 to 302.7 meter-days. The lowest maximum annual event represents a flood that lasted a few hours, whereas the highest value represents a flood that lasted more than 3 months.

Table 2. Catchment areas and values of maximum annual flood exposure during the monitoring period for the 23 sites evaluated for this study. Catchment area was calculated using Illinois Stream Stats (USGS 2012a).

Site #	Watershed	Catchment area (km^2)	Maximum annual FEI	
			Event	Cumulative
10	Mississippi River	356,703.5	18.6	24.1
16	Richland Creek	155.5	0.8	0.9
23	Rock River	24,826.3	48.8	57.7
29	Mississippi River	296,386.3	82.2	88.1
42	La Moine River	812.3	4.6	19.1
44	Rock River	28,006.1	59.5	103.9
46	Galena River	491.0	19.0	19.0
47	Mississippi River	1,845,914.8	185.7	249.5
49	Illinois River	19,454.9	6.4	11.6
50	Edwards River	758.3	4.7	11.0
52	Illinois River	64,997.0	161.9	302.7
54	Sangamon River	7,436.1	42.7	42.7
56	Rock River	21,975.1	31.8	51.4
58	Sangamon River	3,297.2	71.9	146.5
65	Piles Fork	12.2	4.1	12.8
67	Unnamed tributary	6.5	5.1	13.0
68	Big Muddy River	4,034.0	22.8	22.8
71	Jackson Creek	8.8	0.2	0.2
72	Pecatonica River	3,373.1	35.0	64.8
73	Pecatonica River	4,328.3	39.1	61.8
74	Sugar Camp Creek	77.9	1.4	2.5
75	Little Wabash River	564.2	5.1	10.6
77	Little Gallum Creek	32.5	1.4	6.5

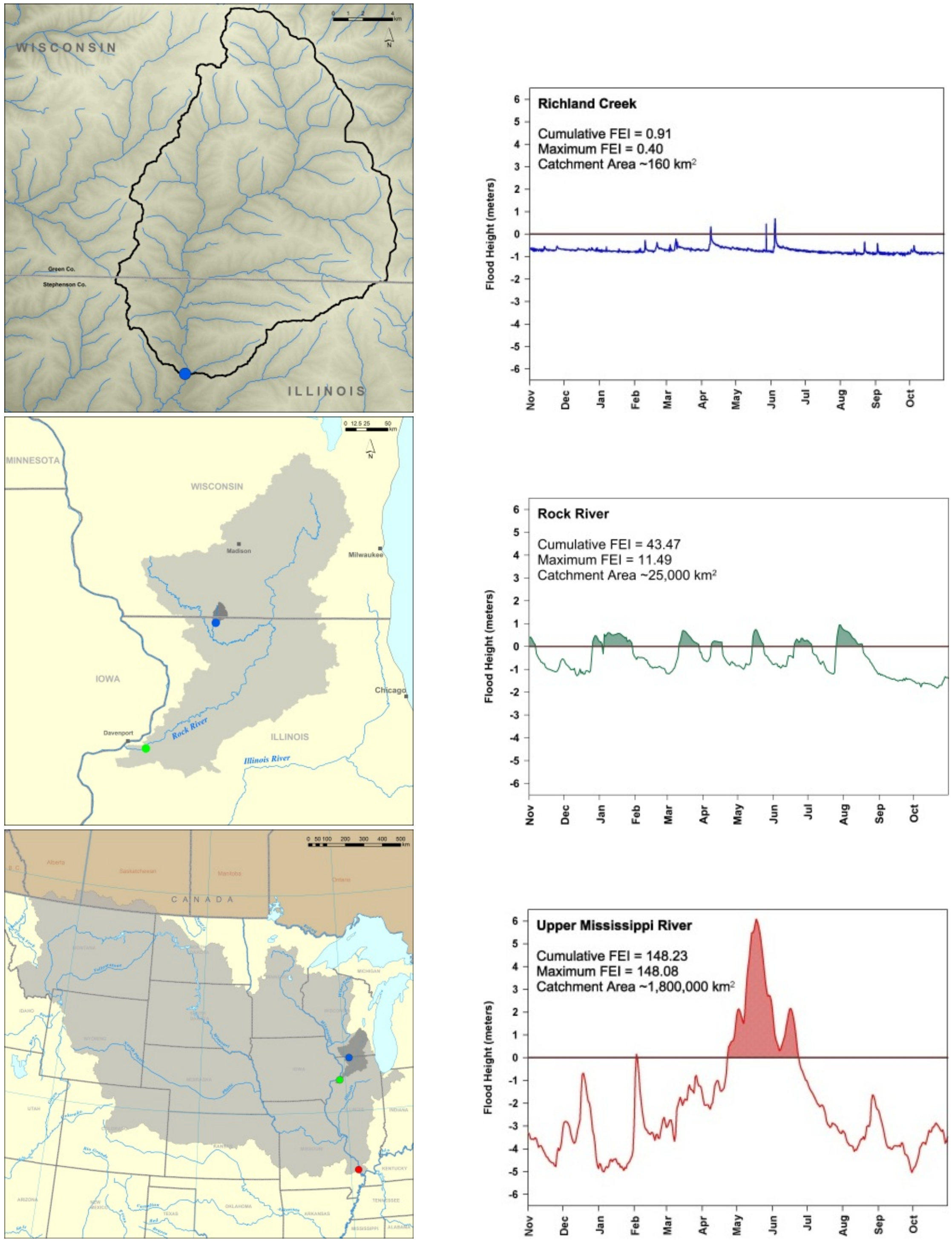


Figure 7. Examples illustrating the application of the flood-exposure index across the range of flood hydrology and watershed size in Illinois. The examples given show the contributing catchment area (left) and hydrograph with corresponding FEI values (right) of headwaters, middle reach, and large-river bottomland wetland mitigation sites (from top to bottom).

For the purposes of this discussion, plant metrics are grouped into four functional categories: community quality (richness, FQI, mean *C*), plant affinity for wet conditions or “plant wetness” (proportion hydrophytes, WIS and PI), life duration (proportion perennial, perennial cover), and native status (proportion native, native cover). The results of the linear regression analyses show that only three of the ten plant metrics (species richness, FQI, and proportion perennials) showed significant correlation with FEI_{max} (Table 3 and Figure 8). Among the community-quality metrics, species richness and FQI show significant inverse correlation with flood exposure. Average annual FEI_{max} accounted for over half of the variability ($R^2 = 0.540$) in average levels of species richness and more than a third of the variability in FQI ($R^2 = 0.375$) and proportion of perennials ($R^2 = 0.430$). Mean *C* was not significantly correlated with flood exposure.

Table 3. Results of the linear regression of various plant-community metrics on $\ln(FEI_{max})$. Bold values indicate significant correlation at Bonferroni-adjusted α = 0.005. Abbreviated headings indicate number of samples (n), degrees of freedom (df), F-ratio (F), coefficient of determination (R^2), and the probability of the F-ratio being this large or greater under the null hypothesis (PR > F).

Dependent Variable	**n**	**Slope**	**Intercept**	**df**	**F**	**R^2**	**PR > F**
ln (richness)	23	–0.1763	4.9021	22	24.63	0.540	**< .0001**
ln (richness) + area*	23	–0.1860	4.8364	22	14.34	0.589	**0.0001**
mean C	23	–0.0686	2.7024	22	1.94	0.085	0.1783
FQI	23	–2.7224	28.2126	22	12.61	0.375	**0.0019**
WIS	23	–0.1412	-1.3709	22	2.98	0.124	0.0991
prop. hydrophytes	23	0.0163	0.7655	22	5.15	0.197	0.0339
prevalence index	15	–0.0316	2.0395	14	0.10	0.008	0.7567
prop. perennial	23	–0.0335	0.7280	22	15.82	0.430	**0.0007**
prop. native	23	0.0047	0.8081	22	0.26	0.012	0.6181
% perennial cover	15	–0.0494	0.8094	14	1.44	0.100	0.2519
% native cover	15	0.0225	0.6614	14	0.19	0.015	0.6693

*The influence of area is minimal, as compared with the model with $\ln(FEI_{max})$ alone.

Contrary to expectation, plant wetness metrics were not significantly correlated with flood exposure. Further, the trends between plant wetness metrics and flood exposure were not consistent. Although not statistically significant, WIS and proportion of hydrophytes did show trends of increasing wetness of the overall plant community with increasing FEI_{max}. However, PI showed no trend with FEI_{max}. The lack of significant relationships of WIS, PI, and proportion hydrophytes with FEI_{max} suggests that sites with higher-magnitude flood exposure do not necessarily have communities of plants with substantially higher affinity for wet conditions. Although this result was unexpected, the data cover a relatively narrow range of the wet end of the full potential range of distribution from uplands to wetlands. The distributions in this study likely reflect the fact that sites are selected and/or designed to be wetlands and generally have plants with affinity for wet conditions regardless of the local flood regime.

Proportion of perennial species showed a strong inverse correlation with FEI_{max}; and proportion perennial cover also showed an inverse trend, but the relationship was not significant. The data support the expectation that high magnitudes of flood exposure cause disturbances that kill perennial species and allow more annual and biennial species to colonize.

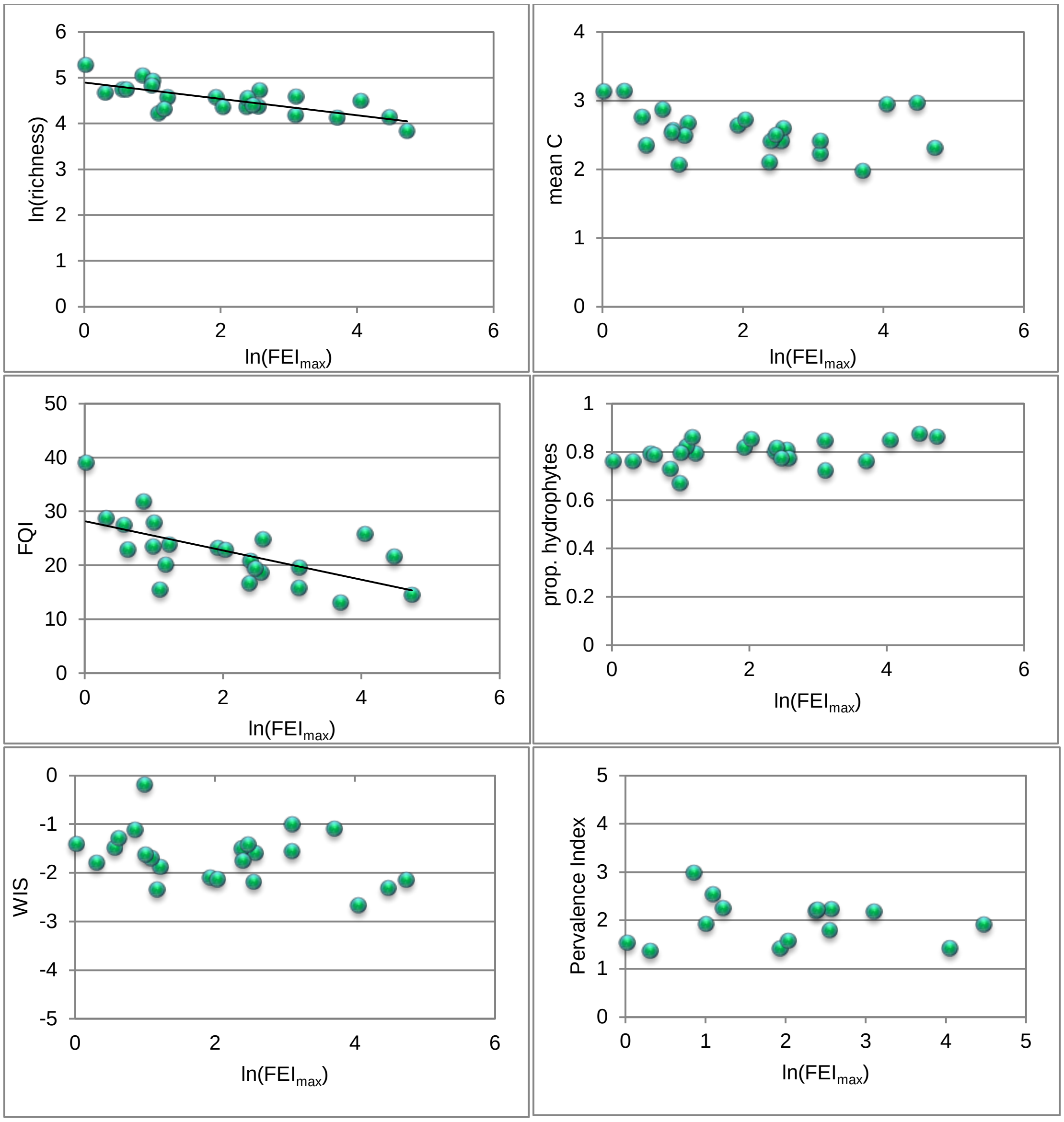


Figure 8. Scatter plots of showing distributions between each of ten vegetation metrics and maximum annual FEI (FEI_{max}). Species richness and FEI_{max} were log-transformed prior to applying the regression model. Best-fit lines are shown in graphs for the three metrics that have statistically significant relationships (Figure 8 continues, next page).

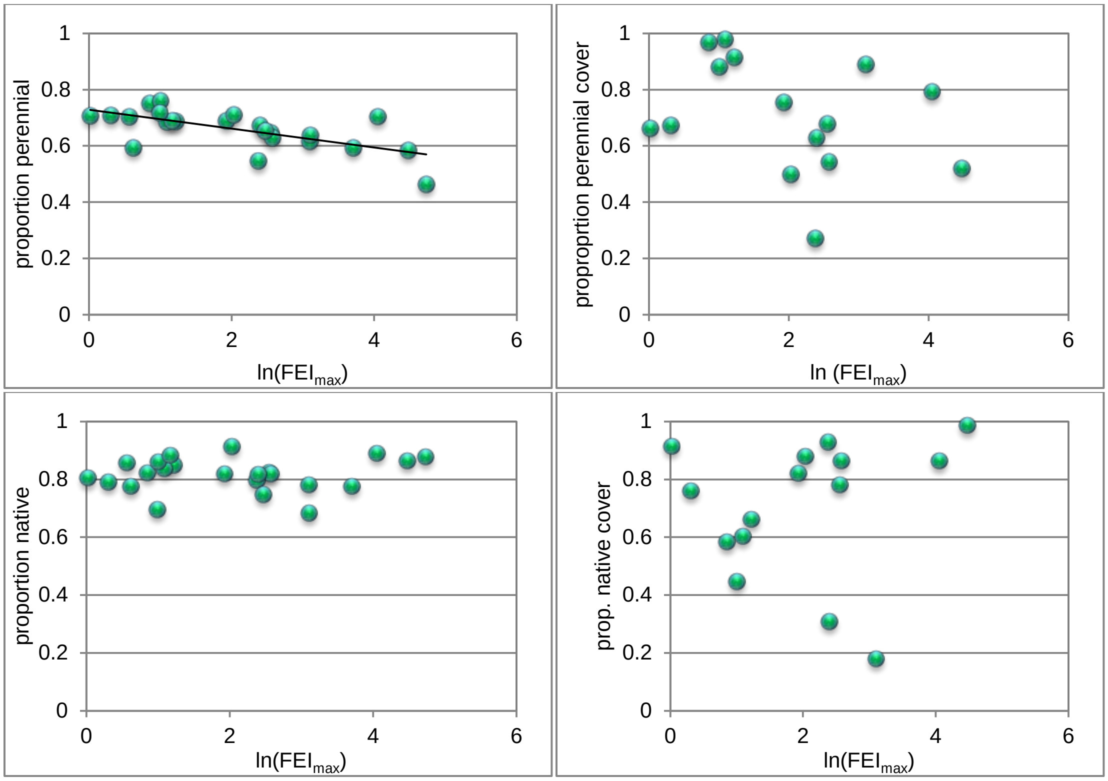
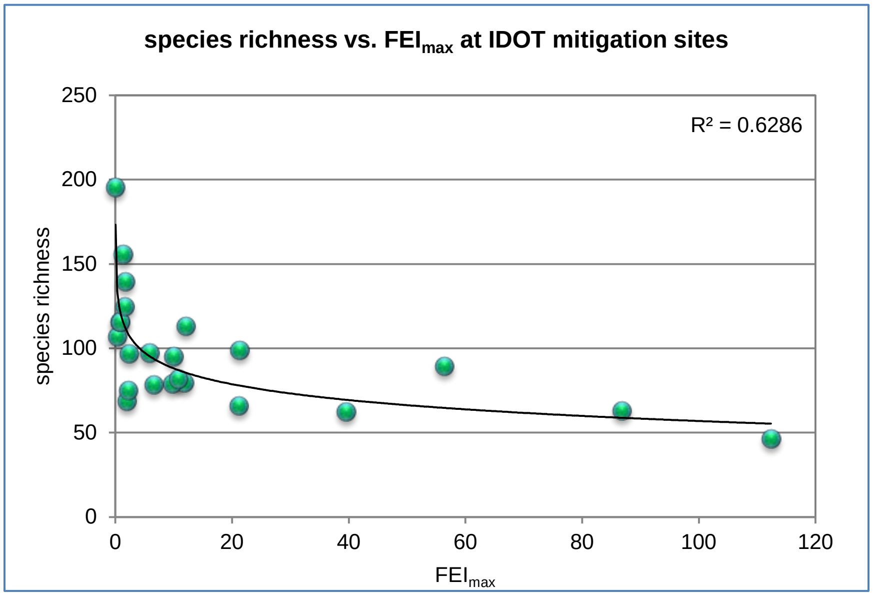


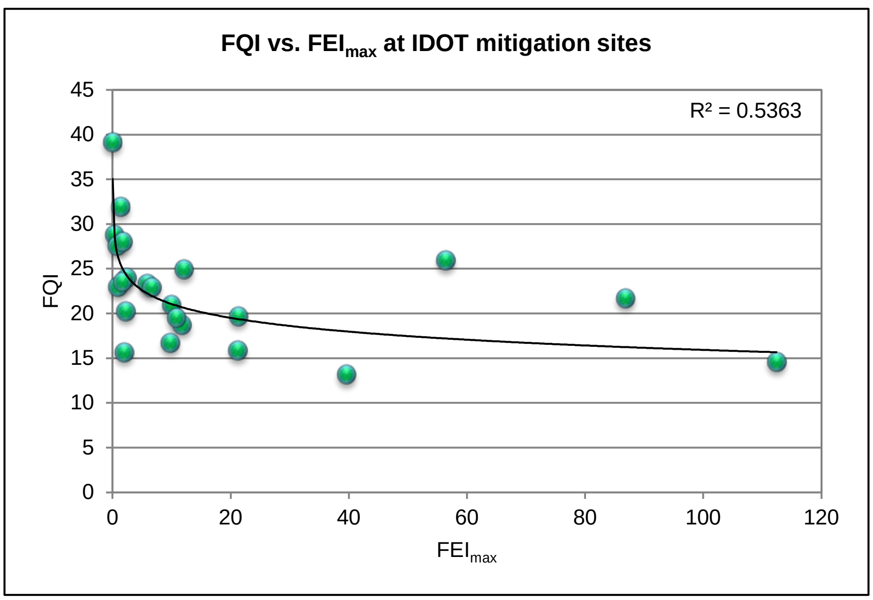
Figure 8. (continued)

Proportion of native species and proportion of native cover showed no significant correlation with FEI_{max}, suggesting that flooding does not have an effect on the occurrence of native species within mitigation sites. We did not have the prior expectation to find a trend in native status of the plant community; and in fact, there was no significant relationship. It is more likely that the native status of an overall community is affected by local factors, such as nearby land use, other hydrological factors, and/or water quality of the water sources supporting wetland sites.

The intermediate disturbance hypothesis (Connell 1978; Bendix 1997) predicts that the highest species richness will occur at intermediate values of flood disturbance; with the distribution of species richness versus disturbance approximating a parabolic curve (see Figure 2), whereas more recent studies have shown that other distributions are common (Mackey and Currie 2001; Hughes et al. 2007). In this study, the data from IDOT wetland mitigation sites fit an inverse logarithmic distribution; on average, sites with lower flood disturbance magnitude have higher numbers of species, and sites with higher magnitudes of flood disturbance have lower numbers of species (Figure 9a). This distribution does not fit the intermediate disturbance hypothesis. Moreover, the relatively strong correlation of species richness and FQI (which incorporates species richness) with flood intensity suggests there is a higher capacity for plant biodiversity in floodplain areas with lower magnitudes of flood exposure (Figure 9b), and the likelihood of attaining the commonly used FQI = 20 standard is significantly lower at higher flood intensities. It is important to note that we considered only the influence of flood disturbance at the landscape scale in this analysis and that the data we analyzed cover a relatively short period in the development of wetland ecosystems. Furthermore, this analysis did not consider the direction of successional trajectories. Additional studies that incorporate other types of disturbances (e.g., drought, changes in water quality, herbivory, disease, and species invasion) over longer periods and considers the pattern and directions of succession would provide information that would improve the predictability of the outcomes of wetland restoration and creation practices.



(a)



(b)

Figure 9. Graphs showing the distributions of (a) average species richness and (b) average FQI at IDOT wetland mitigation sites over the range of average maximum annual FEI values. The shapes of these distributions are not consistent with the intermediate disturbance hypothesis.

4.2 SPECIES TURNOVER VS. FLOOD DISTURBANCE AND SITE AGE

The balance of colonization and local extinction rates over time determines the trajectory of species richness. Data from the IDOT wetland mitigation sites evaluated in this study shows that mean rates of local extinction show no trend as mitigation sites age, while colonization rates steadily decrease (Figure 10). So the general trajectory as determined by all data from all sites, without consideration of flood condition, would yield a species richness trajectory that increases until about year 4 or 5 and flattens thereafter (e.g., see “expected trajectory” in Figure 3). However, many IDOT sites show trajectories that are much more irregular than this general pattern; and irregularities in the trajectories are often associated with flooding (see Figures 4 and 5).

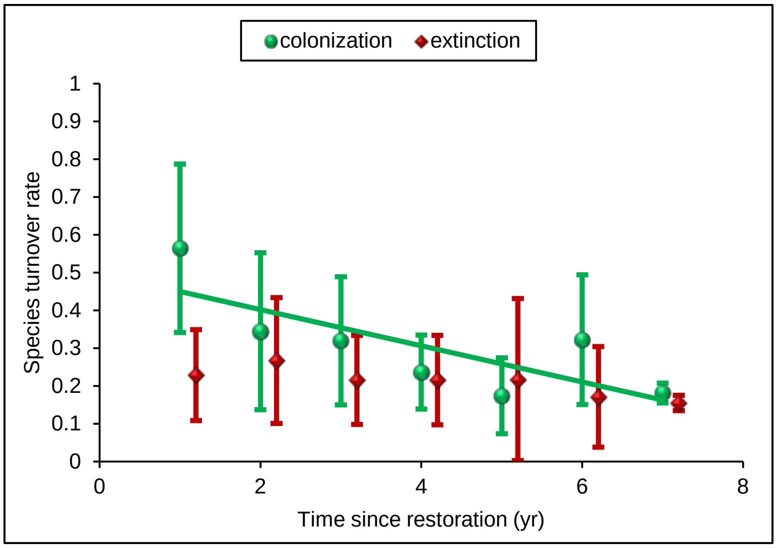


Figure 10. Mean (±SD) colonization (G_p) and extinction (L_p) rates in restored wetlands over time. Colonization rates declined as sites aged, whereas extinction rates remained constant. The figure is intended to illustrate the simple bivariate relationships between turnover rates and time since restoration. Refer to Tables 4 and 5 for results of the full statistical analyses.

Results from the hierarchical mixed modeling showed differentiation in the effect that site age and flood intensity have on various plant-community groups. Results of model selection for species extinction rates showed that loss rates for two species groups (non-hydrophytes and non-natives) were negatively correlated with site age; rates for all species groups, including all species combined, were positively correlated with flood exposure (FEI_{max}); and no species groups showed a correlation of extinction rate with the combined influence of site age and flood disturbance (Table 4). The inverse correlation between the loss rate of non-hydrophytes and site age shows that, in the absence of flooding, species within this group tend to be more resistant to extinction from the local plant community over time. The positive correlation of all species and all species groups with FEI_{max} indicates that loss rates increase with increasing flood exposure for the plant-community as a whole and for each species group; however, the effect is stronger for non-hydrophytes (Figure 11) and non-natives.

Table 4. Results of model selection for species extinction rates. Table entries are parameter estimates for predictor variables included in the selected model for each group of species.

Species group	**Estimated coefficients in the selected model**		
	Site age	**FEI_{max}**	**$Age*FEI_{max}$**
All species		0.025**	
Hydrophytes		0.021**	
Non-hydrophytes	–0.024*	0.055***	
Perennials		0.025**	
Annuals		0.026*	
Natives		0.021**	
Non-natives	–0.017	0.045***	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

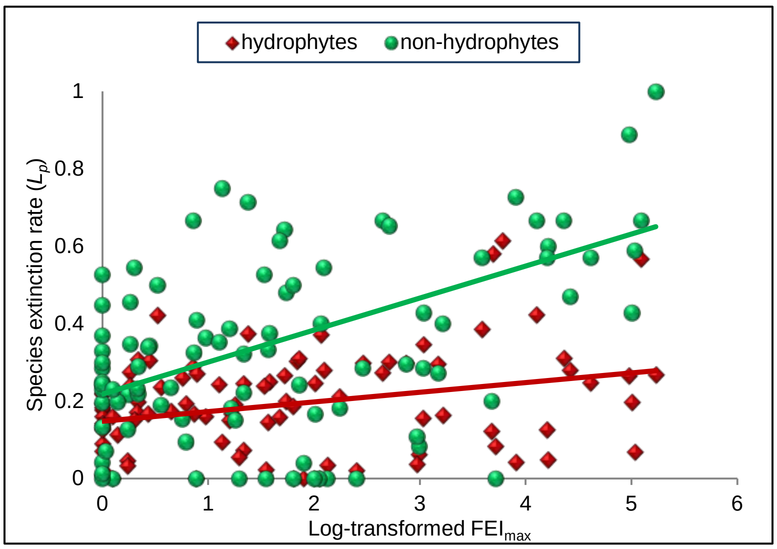


Figure 11. Annual extinction rates (L_p) for hydrophytic and non-hydrophytic plant species vs. annual flood exposure. Although both hydrophytes and non-hydrophytes disappeared from sites following floods, non-hydrophytes were lost from wetland sites at a higher rate during years with high flood exposure. The figure is intended to illustrate the simple bivariate relationships between extinction rates and flood exposure. Refer to Table 4 for results of the full statistical analyses.

Results of model selection for species colonization rates showed that gain rates for hydrophytes, perennials and natives, and all species combined were negatively correlated with site age rates for non-hydrophytes, annuals, and non-natives were positively correlated with FEI_{max} from the previous year; and no species groups were correlated with the combined influence of site age and flood disturbance in the previous year (Table 5). Inverse correlations between gain rates of hydrophytes, perennials and natives, and all species with site age indicate that populations within these groups add fewer species over time, likely as a result of fewer available niches for colonization and increased utilization of available resources. Positive correlations of gain rates for non-hydrophytes, annuals, and non-natives with FEI_{max} from the previous year indicates that gain of species within these functional groups increases with increasing flood exposure in the previous year; and the effect is strongest within non-hydrophyte populations (Figure 12).

Table 5. Results of model selection for species colonization rates. Table entries are parameter estimates for predictor variables included in the selected model for each group of species.

Species group	Estimated coefficients in the selected model		
	Site age	**FEI_{max} for previous year**	**Age*FEI_{max} for previous year**
All species	–0.027***		
Hydrophytes	–0.030***		
Non-hydrophytes		0.032**	
Perennials	–0.034***		
Annuals		0.013	
Natives	–0.031***		
Non-natives		0.020	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

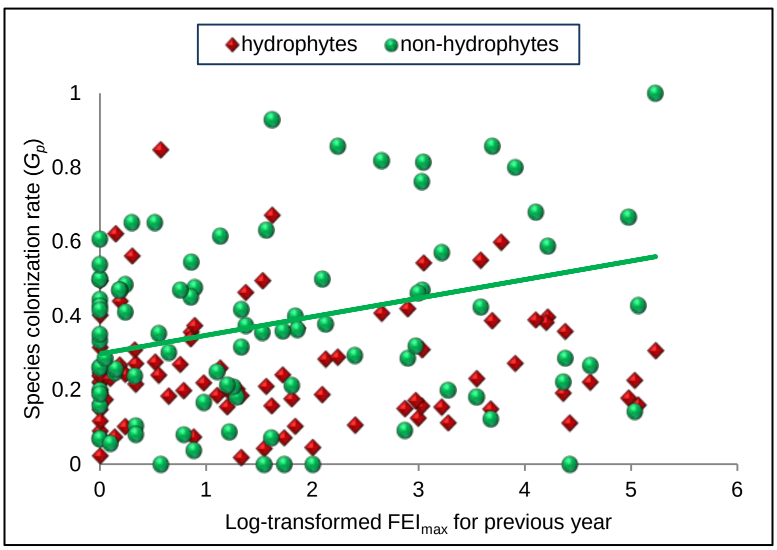


Figure 12. Annual colonization rates (G_p) for hydrophytic and non-hydrophytic plant species vs. flood exposure during the previous year. Non-hydrophytes colonize wetlands at a high rate in the year following a major flood. The figure is intended to illustrate the simple bivariate relationships between colonization rates and flood exposure. Refer to Table 5 for results of the full statistical analyses.

4.3 PERFORMANCE STANDARDS AT SELECTED SITES

Performance standards were compiled from the example mitigation wetlands to determine the effect of intense flooding on the achievement of performance standards. As described in the example in Chapter 2, flooding at the Sangamon County wetland compensation site in 2002 resulted in marked decreases in compliance levels relative to performance standards for planted-tree survival and native and non-weedy species composition (Table 6). The site met the performance standard requiring more than 75% planted-tree survival in 2001 but failed to meet this standard following prolonged flooding in 2002. Tree survival increased again by 2005 due to a combination of replanting and re-sprouting of flood-damaged trees. Because of the prolonged inundation, the area of the site meeting the wetland hydrology criterion was relatively high in 2002. The site was dominated by disturbance-adapted annual plant species throughout the monitoring period (2001–2006) and failed to achieve the standard of more than 90% native and non-weedy species. A sampling visit during 2012 showed that the site was still dominated by disturbance-adapted annuals, perhaps as a result of additional flood disturbance events in recent years.

Table 6. Compliance levels relative to performance standards at the IL Route 29 wetland compensation site from 2001 to 2006. A major flood event occurred at this site in 2002 (gray column). Elevated planted-tree survival in 2005 and 2006 is the result of replanting after flood and ice damage (see e.g., Figure 1b).

Parameter	**Monitoring year**					
	2001	**2002**	**2003**	**2004**	**2005**	**2006**
FEI_{max}	4.02	42.73	1.65	1.36	8.38	0.56
> 75% planted-tree survival	96.5%	72.9%	73.6%	74.0%	94.5%	95.0%
> 90% of species native and non-weedy	56%	25%	36%	54%	57%	46%
No non-native or weedy dominants	not met	N/A	not met	met	not met	not met
2.4 acres meeting wetland hydrology criterion (12.5% of growing season)	N/A	2.4 acres	0.3 acres	2.4 acres	1.6 acres	2.0 acres
> 50% of dominant species hydrophytic	67%	N/A	100%	100%	60%	75%

At the Pecatonica and Freeport wetland compensation sites, flooding in 2008 corresponded with sharp declines in planted-tree survival, species diversity, FQI and/or total vegetation cover (Tables 7 and 8). Although most performance standards that had been met at these sites in 2007 continued to be met in 2008, decreases in vegetation-based metrics, likely resulting from flooding, pushed the sites toward non-compliance. On the other hand, compliance levels increased relative to performance standards for mean WIS, dominance by hydrophytic species, and total area meeting the wetland hydrology criterion. Therefore, in terms of compliance, major floods have both negative and positive impacts.

Table 7. Compliance levels relative to performance standards at the Freeport wetland compensation site from 2007 to 2011. A major flood event occurred at this site in 2008 (gray column).

Parameter	Monitoring year				
	2007	2008	2009	2010	2011
FEI_{max}	0.05	35.04	5.41	7.11	6.46
> 55 planted trees/acre	89.6 trees/acre	78.2 trees/acre	79.3 trees/acre	72.0 trees/acre	76.1 trees/acre
> 50% of species native, non-weedy perennials	25%	42%	41%	59%	58%
No non-native or weedy dominants	not met	not met	not met	not met	not met
15.6 acres meeting wetland hydrology criterion (12.5% of growing season)	12.8 acres	23.3 acres	12.5 acres	8.1 acres	8.0 acres
> 50% of dominant species hydrophytic	50%	100%	60%	67%*	67%*

*Compliance level changes to 100% under the *Midwest Regional Supplement* (USACE 2010a)

Table 8. Compliance levels relative to performance standards at the Pecatonica wetland compensation site from 2005 to 2008. A major flood event occurred at this site in 2008 (gray column).

Parameter	Monitoring year				
	2005	**2006**	**2007**	**2008**	**2009**
FEI_{max}	0.00	0.00	0.10	39.11	10.71
> 80% planted-tree and -shrub survival	27.4%	21.9%	25.7%	11.9%	8.3%
At least 5 planted-tree species 3 planted-shrub species present	6 trees, 5 shrubs	7 trees, 5 shrubs	7 trees, 5 shrubs	5 trees, 3 shrubs	3 trees, 3 shrubs
< 20% dominance by non-native or weedy species	not met	not met	not met	not met	not met
> 60% vegetative cover	> 85%	> 95%	> 95%	> 60%	> 60%
> 30 native species present	105	116	126	77	87
FQI > 20	27.5	28.4	30.3	25.4	23.4
FQI must increase yearly		increase	increase	decrease	decrease
Native mean WIS < 0	–1.6	–1.3	–1.0	–2.8	–1.5
Relative importance value of natives must increase yearly.		decrease	increase	increase	decrease
17.9 acres meeting wetland hydrology criterion (12.5% of growing season)	3.3 acres	6.2 acres	9.4 acres	16.8 acres	5.3 acres
> 50% of dominant species hydrophytic	67%	50%*	60%[†]	75%	100%

*Compliance level changes to 75% under the *Midwest Regional Supplement* (USACE 2010a)
[†]Compliance level changes to 80% under the *Midwest Regional Supplement* (USACE 2010a)

The performance standards in these case studies were evaluated under the 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987). Wetland delineation standards have recently been updated in the regional supplements to the 1987 manual. Therefore, we reevaluated the case studies using the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Midwest Region* (2010a) to determine the impact of these changes. We found very few changes in performance levels (see notes at the bottom of Tables 7 and 8), all of which resulted from the fact that species with a wetland indicator status of FAC- were not considered to be hydrophytic under the 1987 manual but are considered to be hydrophytic under the *Midwest Regional Supplement.* Performance changed from non-compliant to compliant in only one case (Pecatonica site in 2006; Table 8).

CHAPTER 5 CONCLUSIONS

IDOT floodplain wetland mitigation sites cover a wide range of watershed settings and thus are exposed to a variety of flood regimes. The findings of this study showed that at the landscape scale, flood exposure is a significant predictor of the average level of key plant-community metrics commonly used to evaluate replacement of wetland functions. Average annual maximum flood exposure showed significant inverse relationships with three commonly used plant metrics. Magnitude of flood exposure explained over half of the variation for species richness and over a third of the variation in both FQI and proportion perennial species. On average, floodplain wetland mitigation sites with lower flood exposure showed significantly higher species richness, FQI, and proportions of perennial species; therefore, such sites are more likely to attain vegetation-based performance standards based on these metrics, whereas sites with higher flood exposure are less likely to attain performance standards. Also, we found that flood exposure has a significant influence on the rates of local species extinction and colonization at floodplain wetland mitigation sites. For all species groups within the plant community, higher species extinction rates tend to occur as flood intensity increases; however, this effect is strongest for non-hydrophytes and non-native species. Evaluation of the influence of flooding on colonization rates showed that higher species colonization rates tend to occur only for undesirable species groups (i.e., non-hydrophytes, annuals, and non-natives), while decreasing colonization rates for the community as a whole and hydrophytic, perennial, and native species, groups considered desirable for attaining performance goals, are correlated with site age. In summary, these findings showed (1) sites with lower flood exposure appear to have a higher capacity to attain plant-community biodiversity goals; (2) although there is a general tendency for wetland mitigation sites to follow an increasing trajectory of species richness over time, high intensity floods cause punctuated local extinction events and lead to increased colonization rates of undesirable species in the year following the extinction events.

Potential applications of this research are (1) using flood regime in a landscape context to guide floodplain wetland mitigation site selection, with particular consideration for vegetation-based functional replacement goals; (2) adjusting mitigation planting plans based on existing flood exposure; and (3) adjusting mitigation site design to alter the depth and duration of flooding where appropriate. Of these, the first has the most immediate applicability. For example, if the goal of a particular wetland mitigation project is to attain high species richness, FQI, or proportion of perennials, then emphasis might be placed on selecting a site with low levels of flood intensity because the likelihood of attaining wetland plant diversity goals increases with decreasing flood intensity. Alternatively, if there is an opportunity to restore a large-river bottomland, then the expectation of high FQI or proportion of perennials in frequently flooded portions of the floodplain would be unrealistic; and differentiation of functional goals within the floodplain may need to be considered.

Currently, wetland mitigation performance is judged largely on meeting primary wetland determination criteria and vegetation-based performance standards. The findings from this study showed that the magnitude of flood intensity has a significant influence on the performance levels of some vegetation metrics commonly used to evaluate wetland mitigation progress, namely species richness, FQI, and proportion of perennials. This suggests that performance standards applied to all mitigation wetlands without consideration of hydrologic context will be too broadly defined to provide a meaningful evaluation of progress for floodplain wetlands and perhaps other wetland types. For example, a performance standard requiring an FQI score greater than 20 may be overly lenient in some upper watershed locations that have a capacity for greater species diversity but overly stringent over portions of bottomlands in the floodplains of major rivers. Therefore, it would be appropriate to develop performance standards that consider the influence of hydrologic regime on the level of site performance, based on a given hydrologic setting. However, a more extensive study of a larger number of wetlands, including natural reference wetlands, which vary in hydrologic setting, would be required before recommending specific performance standards.

This study focused on the landscape-scale influence of flood disturbance on plant biodiversity, one of many important wetland functions. We would expect the influence of flooding on other wetland functions (e.g., sediment retention, biogeochemical cycling, and water quality) would show different patterns of response. Therefore, our conclusions are limited to only the influence on plant communities; and additional study is necessary to address other wetland functions. Further, additional data are needed to develop models that can reliably estimate hydrologic requirements for particular plant communities, species groups, or species of concern at the site level. Studies relating the changes in plant communities to flood exposure (or other hydrologic or biogeochemical variables at the site level for mitigation sites and natural wetlands) would help to establish the range of conditions and factors of influence on other functions at natural wetland and wetland mitigation sites. Such studies would improve the predictability of the outcomes of particular approaches to wetland mitigation. Further, we recommend the continuation of tree-survival studies that would provide data that could be used to develop models to inform the mitigation planting plans in floodplain settings.

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APPENDIX EXAMPLES OF PERFORMANCE STANDARDS ISSUED FOR IDOT MITIGATION PROJECTS

UASCE–Chicago (USACE 2012b)

Parameter	Performance Standard
Community composition	At least 50% of the required minimum number of species shall occur at a 10% frequency or greater, within each plant community zone or area.
Mean C	≥ 3.5 in each plant community.
FQI	≥ 20 in each plant community.
Mean WIS	(based on regional wetland indicator status) must indicate the presence of a wetland
Vegetation cover	No area greater than 1 m^2 will be devoid of vegetation after 5 years, unless previously approved.
Non-native and weedy species	None of the three most dominant plant species in any of the wetland community zones may be non-native species or weedy species, including but not limited to *Typha angustifolia*, *Typha* × *glauca*, *Phragmites australis*, *Lythrum salicaria*, *Salix interior,* or *Phalaris arundinacea*, unless otherwise indicated on the approved mitigation plan. These species shall not cumulatively comprise more than 5% of the total percent cover (not relative cover) for each community.
Native perennials	The native perennial species within each wetland plant community shall represent at least 80% of the total dominance measure. A lower percent native perennial species of the total dominance measure may be acceptable if it is demonstrated with transect data that the remaining dominance percentage is by native annual and biennial wetland plant species and the FQI and mean C standards are exceeded.

USACE–Louisville (IDOT, in review)

Parameter	Performance Standard
Tree stock	No one tree species makes up more than 25% of the forest stock.
Herbaceous planting	No one herbaceous species make more than 30% of the final planting.
Tree survival	90% of RPM trees survive, 50% of bare-root seedlings survive.
Vegetation cover	Planted herbaceous species must account for 70% of cover.
WIS	70% FAC or wetter, for herbs at least 70% of cover FAC or wetter

Illinois DNR and USACE St. Louis District (IDOT 2009)

Parameter	Performance Standard
Tree stocking	217 live, bare-root seedlings/ac or 54 saplings/ac (with 2-year tracking)
FQI	> 10 after 2 and > 20 after 5 years
Mean WIS	Indicative of a wetland based on the delineation manual
Non-native and weedy species	at least 50% non-weedy, native after 2 and 80% after 5 years None of the three most dominant plants in any stratum must be non-native or weedy species

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