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RESEARCH

An Assessment of Long-Term Compliance with Performance Standards in Compensatory Mitigation Wetlands

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Abstract Under the US Clean Water Act, wetland restoration is used to compensate for adverse impacts to wetlands. Following construction, compensation wetlands are monitored for approximately 5 years to determine if they comply with project-specific performance standards. Once a compensation site complies with performance standards, it is assumed that the site will continue to meet standards indefinitely. However, there have been few assessments of long-term compliance. We surveyed, in 2012, 30 compensation sites 8–20 years after restoration to determine whether projects continued to meet performance standards. Additionally, we compared floristic quality of compensation sites to the quality of adjacent natural wetlands to determine whether wetland condition in compensation sites could be predicted based on the condition of nearby wetlands. Compensation sites met, on average, 65% of standards during the final year of monitoring and 53% of standards in 2012, a significant decrease in compliance. Although forested wetlands often failed to meet standards for planted tree survival, the temporal decrease in compliance was driven by increasing dominance by invasive plants in emergent wetlands. The presumption of continued compliance with performance standards after a 5-year monitoring period was not supported. Wetlands restored near better quality natural wetlands achieved and maintained greater floristic quality, suggesting that landscape context was an important determinant of long-term restoration outcomes. Based on our findings, we recommend that compensation wetlands should be monitored for longer time periods, and we suggest that nearby or adjacent natural wetlands provide good examples of reasonably achievable restoration outcomes in a particular landscape.

Keywords Compliance · Floristic quality · Monitoring · Vegetation · Wetland mitigation · Wetland restoration

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Introduction

Biodiversity offsetting and compensatory mitigation strategies are increasingly being used to replace biodiversity and ecosystem services lost as a result of development activities (Madsen et al. 2010; McKenney and Kiesecker 2010). These strategies rely on ecological restoration to provide resources that are equivalent to those, which were lost or degraded. However, ecosystem structure and function are complex and context-dependent, and as a consequence, restoration outcomes are often unpredictable (Maron et al. 2012; Palmer and Filoso 2009; Suding 2011). For example, Matthews and Spyreas (2010) tracked plant community changes in compensation wetlands in Illinois, and found that initially successful restorations eventually failed to meet project objectives due to non-native plant species invasion. Thus, a critical question is whether compensation sites, which are often evaluated based on short-term assessments, continue to meet expectations over the longer term.

Under US Clean Water Act, Section 404(b)(1) Guidelines, adverse impacts to wetlands and streams can be compensated for by creating, restoring, or enhancing wetlands or aquatic resources elsewhere (Corps and EPA 1990; EPA 1980). This practice of compensatory mitigation is in part responsible for reversing the historic trend of wetland loss in the United States (Dahl 2011). Compensation for wetland loss is considered to be adequate only if a project attains certain performance standards by the end of a prescribed monitoring phase. There is a presumption that compensation sites, once they comply with these performance standards, have developed to a state of relative equilibrium, and thus an early assessment should be predictive of future condition. However, there have been few long-term assessments of the performance of compensation sites. Here, we report on the condition of 30 compensation sites several years after mandatory monitoring concluded, to determine whether these projects continued to meet regulatory performance standards.

Wetland conversion is regulated under the US Clean Water Act, Section 404, which is administered by the US Army Corps of Engineers (Corps) with oversight from the US Environmental Protection Agency (EPA). Executive agency regulations have established that ecological restoration can be used to mitigate impacts to wetlands in cases where adverse impacts cannot be avoided or minimized (Corps and EPA 1990; EPA 1980). Compensation projects permitted by the Corps are evaluated based on project-specific performance standards. Performance standards usually require that a compensation site meets the three criteria of a jurisdictional wetland as defined by the Corps (Environmental Laboratory 1987): the presence of hydric soils, hydrophytic vegetation, and wetland hydrology. Additional standards are established on a project-by-project basis, often with vegetation quality as a central concern (Breaux and Serefiddin 1999; Cole and Shafer 2002; Matthews and Endress 2008; Streever 1999; Reiss et al. 2009).

The provider of a compensation site is required to submit monitoring reports to the Corps which describe the condition of the wetland and progress toward meeting performance standards (Corps and EPA 1990, 2008). Compensation sites are typically monitored annually for a period of 5 years (NRC 2001), but the length of the monitoring period is flexible. The current mitigation rule from the Corps and EPA (Corps and EPA 2008, p. 19679) states:

> The mitigation plan must provide for a monitoring period that is sufficient to demonstrate that the compensatory mitigation project has met performance standards, but not less than five years. A longer monitoring period must be required for aquatic resources with slow development rates (e.g., forested wetlands, bogs). Following project implementation, the district engineer may reduce or waive the remaining monitoring requirements upon a determination that the compensatory mitigation project has achieved its performance standards. Conversely the district engineer may extend the original monitoring period upon a determination that performance standards have not been met or the compensatory mitigation project is not on track to meet them.

Thus, the rule presupposes that once a project attains its performance standards it will continue to meet those standards indefinitely, implying that compensation projects follow a steady, increasing restoration trajectory toward an equilibrium state. Early monitoring provides information concerning the starting condition of the wetland, and although this may provide insight into any problems with its construction (e.g., improper hydrology, presence of invasive species), short-term monitoring does not guarantee long-term compliance or successful restoration (Matthews 2015; Zedler and Callaway 1999).

The challenges in restoring or creating wetlands that are ecologically equivalent to naturally occurring wetlands are well documented (Kentula 2000; NRC 2001; Race and Fonseca 1996; Zedler 1996). Problems include the lack of appropriate monitoring (Hornyak and Halvorsen 2003; Kentula et al. 1992; Sifneos et al. 1992), regional net loss of wetland area (Allen and Feddema 1996; Morgan and Roberts 2003; Sudol and Ambrose 2002), and failure to comply with performance standards (Brown and Veneman 2001; Cole and Shafer 2002; Kozich and Halvorsen 2012; Hill et al. 2013, Matthews and Endress 2008; Reiss et al. 2009; Wilson and Mitsch 1996). Compensation wetlands often differ structurally and functionally from natural reference wetlands (Balcombe et al. 2005; Hossler et al. 2011; Peralta et al. 2010). However, few longitudinal studies of the performance of compensation sites have been conducted (Morgan and Hough 2015; but see Gutrich et al. 2009; Matthews and Endress 2008; Spieles et al. 2006). The present study is the first longitudinal study to assess long-term compliance with performance standards, beyond the timeframe typical of site monitoring, in a large number of compensation wetlands.

Wetlands restored in higher quality landscapes or adjacent to existing high quality remnant wetlands may be more likely to achieve and maintain restoration goals. However, compensation wetlands are often constructed in landscapes with intensive human land use and few high quality remnant wetlands. Wetlands restored in these anthropogenically degraded landscapes are subjected to multiple environmental stressors, including increased input of nutrients and pollutants and increased propagule pressure from invasive species (Ehrenfeld 2000; Simenstad et al. 2006). Thus, long-term compliance with performance standards may depend on the context within which compensation wetlands are restored.

We address two research objectives. First, we investigated the condition of 30 compensation sites to determine if they continued to meet or exceed original regulatory performance standards beyond the monitoring period. If monitoring were of sufficient duration to forecast long-term compliance, then a compensation site should continue to achieve at least the performance standards that it achieved at the end of site monitoring. We compared compliance during the final year of monitoring with current condition 8–20 years after restoration. Our second objective was to determine whether long-term performance in compensation wetlands was related to the ecological quality of nearby natural wetlands. We compared floristic indicators, commonly used to establish performance standards, with those measured at adjacent natural wetlands. We expected that floristic indicators in the compensation sites would increase through time and be positively correlated with the condition of nearby natural wetlands.

Methods

Study Sites and Design

Research sites consisted of 30 permittee-responsible compensation wetlands, as well as 15 natural wetlands that were adjacent to 15 of the compensation sites (Fig. 1). Compensation sites were constructed between 1992 and 2004 and included 15 emergent, 13 forested, and 2 combined emergent and forested wetlands. The compensation wetlands had been restored to compensate for wetland impacts resulting from Illinois Department of Transportation (IDOT) road construction and maintenance activities. These 30 sites were selected from a larger set of 54 IDOT compensation wetlands based on site access and availability of previous monitoring data.

Each of the 15 natural wetlands was located within 35 m of a paired compensation site. We were unable to locate appropriate, adjacent reference wetlands for all 30 compensation sites. Instead of selecting high quality reference wetlands to represent the highest attainable condition in the region, we selected natural wetlands adjacent to the compensation sites because they represent likely wetland condition given the landscape context. Natural wetlands and paired compensation sites were matched by type (i.e., forested or emergent).

This study consisted of two sets of comparisons. First, we compared the attainment of performance standards in the full set of 30 compensation wetlands at the end of the official monitoring periods to the attainment of performance standards in 2012. Second, we compared floristic quality between the subset of 15 compensation wetlands and their paired reference wetlands. Natural wetlands were surveyed in 2012 only.

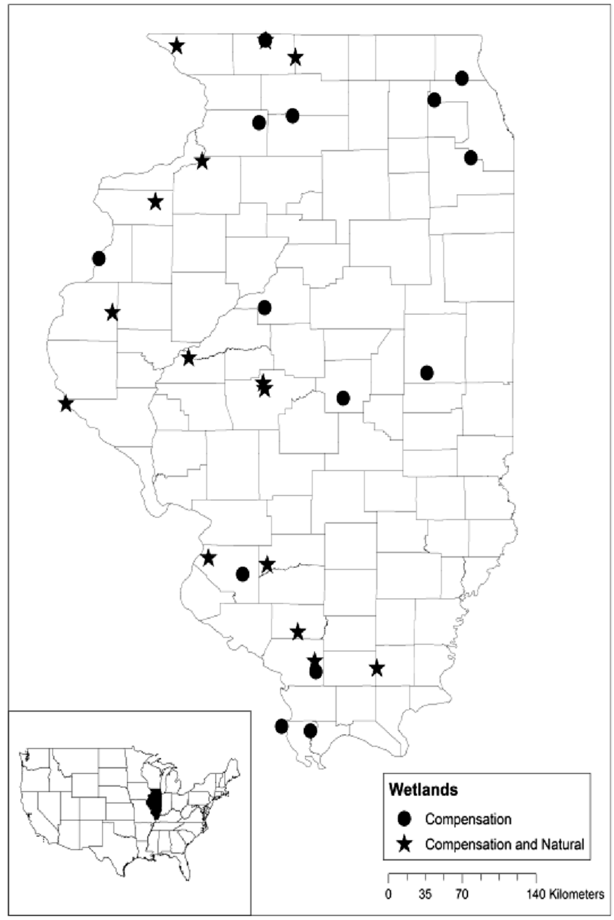

Fig. 1 Locations of wetland compensation sites and paired natural wetlands within IL, USA

Original Monitoring of Performance Standards

The 30 compensation sites, following construction, were monitored by staff from the Illinois Natural History Survey (INHS), and were last monitored by INHS between 1996 and 2009. We obtained original monitoring reports and data for the compensation sites from INHS. Performance standards varied among the 30 compensation sites, and monitoring methods varied among sites according to permit conditions. We grouped performance standards into 9 categories of restoration goals: (1) restore jurisdictional wetland, (2) dominant species should be native and/or non-weedy, (3) minimum percentage of species should be native, non-weedy, and/or perennial, (4) planted tree survival, (5) minimum cover by hydrophytes, (6) minimum vegetation cover, (7) minimum planted herb performance, (8) floristic quality and (9) "other" (including measures of the physical structure of the vegetation, sediment accumulation, and standards related to buffer zones). Additional details of monitoring for individual performance standards are described in the paragraphs below.

As required for most compensation sites, jurisdictional wetland areas within all project sites were delineated following US Army Corps of Engineers (ACOE) methodology. To be considered a wetland, positive evidence is required for the presence of hydrophytic vegetation, wetland hydrology and hydric soils (Environmental Laboratory 1987). For each compensation wetland we noted whether jurisdictional wetland had been restored by the final year of site monitoring.

Vegetation at the compensation wetlands was monitored as required under the mitigation agreements. INHS conducted a complete inventory of all plant species at each site. In addition, for 19 sites INHS was required to quantify the percent coverage of plant species. To accomplish this, vegetation surveys were conducted using 1 or 0.25 m^2 quadrats placed at even intervals along representative transects through the project area. All vascular plants within the quadrats were identified and assigned a cover class (<1%; 1–5%; 6–25%; 26–50%; 51–75%; 76–95%; 96–100%), based on a visual estimate of the percent of coverage of the species within the quadrat (Daubenmire 1959).

Twenty-four sites had performance standards related to the identity of the dominant plant species at the compensation site. For example, permit conditions sometimes required that the dominant species must be native or established minimum levels of dominance for native or "non-weedy" plant species. For the purposes of this study, we defined dominant species based on the 50/20 Rule (Corps 2010). Following this method, dominant species are the most abundant species that individually or collectively account for more than 50% of the total coverage in a stratum (herb, sapling/shrub, tree, or woody vine layers), plus any other species that by itself accounts for at least 20% of the total coverage for the stratum.

Four sites had performance standards which required Floristic Quality Assessment (Swink and Wilhelm 1994). Floristic Quality Assessment is based on Coefficients of Conservatism, C, which are numeric scores assigned to each species in a region by expert botanists. A species' C value, which ranges from 0 to 10, is based upon the likelihood that it would be found exclusively in an undegraded natural area. A species that is indicative of less impacted sites receives a higher C value, whereas a species which frequently occurs in degraded sites is assigned a lower C value. For this study, we used C values assigned by Taft et al. (1997) for the Illinois flora. To conduct Floristic Quality Assessment, INHS staff inventoried plant species during a thorough search at each compensation site, and individual species C values were used to calculate floristic quality metrics. Although only four sites had performance standards based on Floristic Quality Assessment, these inventories were conducted at all sites. Performance standards were based on two metrics: the native mean Coefficient of Conservatism (Mean C) for the site and the native Floristic Quality Index (FQI), which is calculated by multiplying the Mean C by the square root of the number of native species at a site (Swink and Wilhelm 1994). Some authors (e.g. Bourdaghs et al. 2006; Cohen et al. 2004) have advocated assigning $C = 0$ to non-native species and multiplying Mean C by the square root of the total number of plant species to calculate FQI. Although this is a common approach, we did not include non-natives in our calculations because doing so would have been inconsistent with the original performance standards for our study sites.

Nineteen sites had performance standards which required that some minimum percentage of the site's total flora should be comprised of native, non-weedy, and/or perennial species. Native status of species was based on Mohlenbrock (2002), with the exception of *Phalaris arundinacea* and *Typha* spp. (*T. angustifolia* and *T.* x *glauca*), which we considered to be non-native to this region due to uncertain origin and likely hybridization between native and non-native species or genotypes (Lavergne and Molofsky 2004; Shih and Finkelstein 2008). For consistency across projects, we defined "weedy" species as species with C values of 1 or 0 (Taft et al. 1997).

Twenty-two of the 30 wetlands had performance standards which required an evaluation of the survival of planted species; 16 sites were monitored for planted tree survival, and 6 for the persistence (presence or absence) of planted herbaceous species. Performance standards based on survival of planted trees required an inventory of surviving trees at the site. To quantify performance, the number of surviving planted trees found at the site was divided by the number of trees originally planted.

Wetland Revisits

During a 5-week period in June and July of 2012 we resurveyed the 30 compensation wetlands as well as the 15 natural wetlands. The amount of time between the last official monitoring visit and our revisits ranged from 3 to 16 years (median = 9 years). At all 45 sites, we sampled vegetation using methods similar to those used during the initial monitoring. We first established a baseline parallel to the longest edge of the wetland. We divided the baseline into four equal lengths, and within each segment we randomly placed one transect perpendicular to the baseline and spanning width of the wetland. We quantitatively sampled vegetation within ten 0.25 m^2 quadrats placed at even intervals along each of the four transects, for a total of 40 quadrats per wetland. All vascular plants within the quadrats were identified and assigned a cover class, as described above in *Original monitoring of performance standards*. Additionally, we conducted a thorough inventory of all plant species at each site during a timed search (at least 30 min per site). In summer 2012 and 2013 we relocated and counted surviving planted trees at the compensation sites that had performance standards for planted tree survival. We assumed that in the absence of major disturbances to sites, the area of jurisdictional wetland would not change drastically between the end of monitoring (EOM) and the time of our site revisits. Therefore, we noted the presence (or absence) of jurisdictional wetland but did not re-delineate wetland boundaries at compensation sites.

Statistical Analysis

We used a nonparametric Wilcoxon signed rank test to test the null hypothesis that there was no difference, between time periods, in the percentage of performance standards that were successfully achieved. We chose the signed rank test rather than a paired *t*-test because the difference between the number of performance standards that a compensation wetland achieved in 2012 and the number of standards it achieved at the end of site monitoring was not normally distributed (Shaprio-Wilk $W = 0.928$, $n = 30$, $p < 0.04$). We also evaluated compliance rates separately for the nine categories of performance goals (see *Original monitoring of performance standards*). To determine which of these goals were most likely to be met we tallied the number of sites with performance standards related to each goal and the number of sites meeting or exceeding their site-specific performance standards in each time period. We did not analyze individual performance goals using formal statistical tests due to the small sample size for most goals.

We used linear mixed effects models, as implemented in the nlme package in R (Pinheiro et al. 2016; R Development Core Team 2016), to determine the effects of time period (EOM vs. 2012) and the floristic quality of the adjacent reference wetland on floristic quality in compensation wetlands. This analysis was restricted to the 15 compensation wetlands for which we had a paired reference wetland. Because quantitative vegetation sampling was not conducted at all sites during the initial monitoring period, we restricted these analyses to three metrics that could be calculated for both compensation sites and natural wetlands based on site species lists: percentage of native, non-weedy, perennial species; Mean *C*; and FQI. Models for each floristic indicator included the main effects of time period (categorical: EOM or 2012) and the value of the indicator in the paired reference wetland (continuous), as well as the interaction between time period and the value of the indicator in the reference wetland. Site identity was included as a random effect to account for repeated measures at the compensation sites. We assumed that the floristic quality of the natural wetlands did not change significantly between the EOM and 2012.

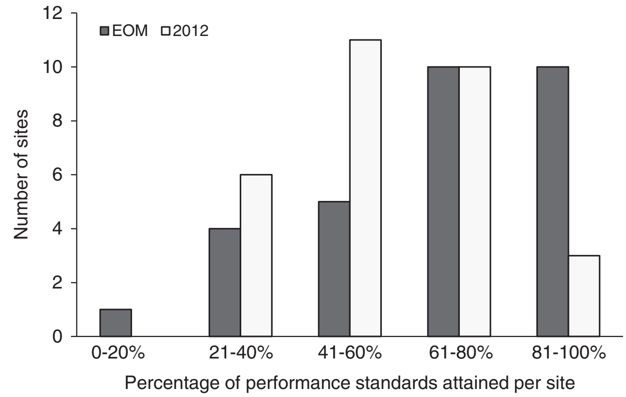

Fig. 2 Frequency histograms representing the distribution of percentage of performance standards satisfied in 30 compensation sites. Results are shown for both the end of the original monitoring period (EOM) and for 2012–2013

Results

Of 30 compensation sites, only 3 met more of their performance standards in 2012 than during the final year of monitoring, whereas 13 met fewer performance standards. On average, compensation sites met 65% of their performance standards during the final year of monitoring and 53% in 2012, which was a statistically significant decrease in performance standard achievement between sample periods (Fig. 2; Wilcoxon signed rank test: $n = 30$, $S = 47.5$, $p = 0.022$). This decrease was driven by emergent wetlands, which met an average of 71% of performance standards at the EOM, but only 54% in 2012. In contrast, forested wetlands met an average of 52% of performance standards in both time periods.

Our assessment of individual standards (Fig. 3) indicated that the decrease in achievement of performance standards was driven primarily by the increasing dominance of non-native and invasive plant species through time. During the final year of site monitoring 9 of 24 compensation sites met dominant species standards, but by 2012 only 1 of 24 sites met its standard requiring dominance by native and non-weedy plant species. The two most frequent dominant plants in 2012 were invasive species; *Phalaris arundinacea* was a dominant species in 9 of the 24 sites, and *Typha angustifolia*/x *glauca* was a dominant in 7 sites. Other dominant non-native species included *Festuca arundinacea* and *Lonicera japonica*; each was among the dominant species in 3 of the 24 sites.

Standards related to the survival or establishment of planted trees and herbaceous species were also often unmet at the EOM and remained unmet in 2012 (Fig. 3). By the time of our resurveys, planted species standards were achieved for planted herbs in only 1 of 6 sites, and for planted trees in only 1 of 15 sites. Although planted tree

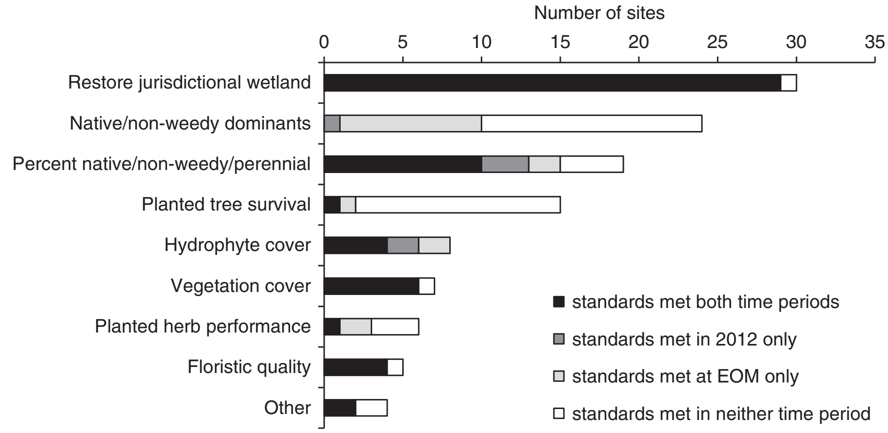

Fig. 3 Number of compensation sites with performance standards related to nine categories of restoration goals, and number of sites meeting those goals at the end of site monitoring (EOM) and in 2012–2013

Table 1 Average (±standard error) floristic quality indicators in compensation wetlands at the EOM, compensation wetlands in 2012, and reference wetlands, and results of linear model for the effects of time period (EOM or 2012), reference site quality, and their interaction

Response variable	Average (±S.E.)			$F_{1,13}$		
	EOM	2012	Reference	Time period	Reference quality	Time period × reference quality
Percent native, non-weedy, perennial	48.7 (2.5)	54.8 (3.2)	60.1 (2.5)	2.92	3.19	1.96
Mean *C*	2.20 (0.12)	2.31 (0.14)	2.47 (0.11)	0.77	9.52**	1.47
FQI	21.2 (1.8)	18.7 (1.2)	16.4 (1.0)	4.92*	7.73*	1.05

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

survival was often poor, survival varied greatly among sites in 2012–2013, ranging from 0 to 85% survival.

Performance standards requiring that a minimum percentage of the wetland's flora should be native, non-weedy, and/or perennial species were met in 12 of 19 sites at the EOM and 13 of 19 sites in 2012 (Fig. 3). Most sites complied with standards related to floristic quality metrics (Mean *C* and/or FQI) and the establishment of vegetation cover and/or hydrophyte cover, achieving those standards in one or both time periods (Fig. 3). Jurisdictional wetland was restored or created in most sites (29 of 30), and these sites continued to meet jurisdictional standards in 2012 (Fig. 3).

Mean *C* and percentage native, non-weedy, perennial species were greater, and FQI was lower, on average, in reference wetlands compared to compensation wetlands (Table 1). Both Mean *C* and FQI increased significantly with increasing quality of the adjacent reference wetlands (Table 1, Fig. 4). Mean *C* and percentage native, non-weedy, perennial species tended to increase, but not significantly, in compensation wetlands between the EOM and 2012. In contrast, FQI decreased significantly in compensation wetlands between time periods (Table 1, Fig. 4). The lack of significant interactions between time period and reference wetland quality suggests that the relationship between floristic quality in the compensation sites and the paired reference wetlands remained consistent between the EOM and our revisits. These trends were similar regardless of whether non-native species were excluded from or included in the calculations of Mean *C* and FQI (data not shown).

Discussion

A specific objective of this research was to determine whether compensation wetlands achieved performance standards many years after site monitoring ended. We found, for emergent wetlands, that compliance with performance standards declined after monitoring ended. Thus, compliance with performance standards by the end of the monitoring phase does not guarantee continued performance at the same level. A second objective was to determine whether long-term performance in compensation wetlands was positively correlated with the ecological condition of adjacent wetlands. We found that wetlands restored near better quality natural wetlands achieved and maintained greater floristic quality, suggesting that landscape context was an important determinant of long-term restoration outcomes.

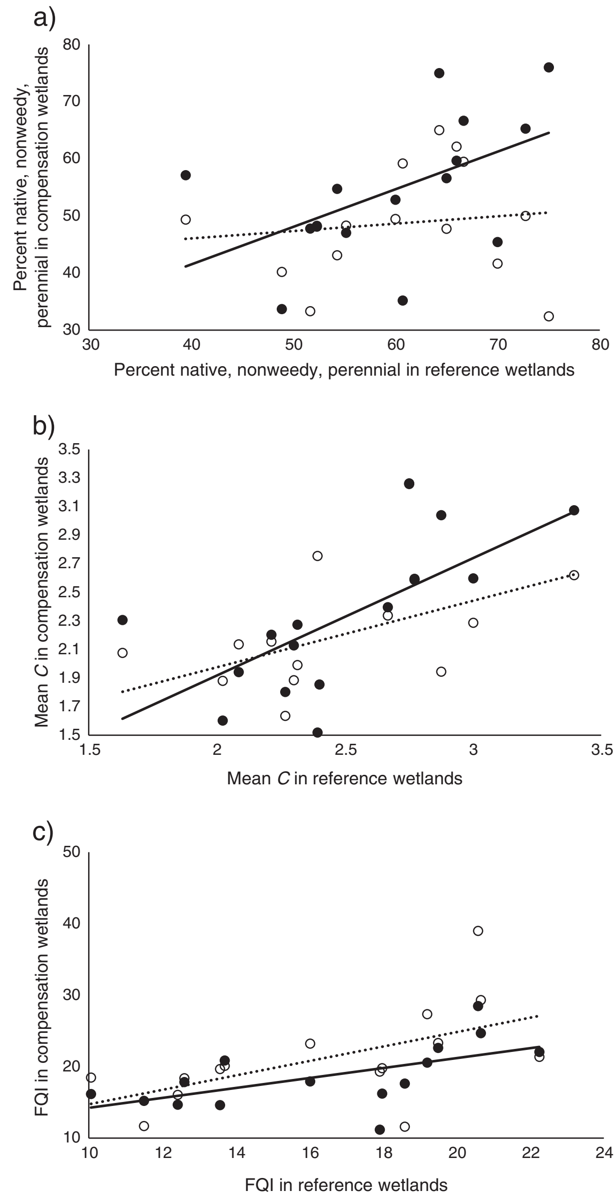

Fig. 4 Relationship between floristic quality of compensation wetlands and the floristic quality of an adjacent natural wetland, at the end of site monitoring (EOM; *open circles*, *dotted line*) and in 2012 (*closed circles, solid line*). Floristic quality indicators included percentage native, non-weedy, and perennial plant species (**a**), Mean Coefficient of Conservatism (**b**), and Floristic Quality Index (**c**)

Long-Term Achievement of Performance Standards

The performance standards with which sites were most likely to become non-compliant *after* official monitoring ended were standards requiring that dominant species not be non-native or weedy. Non-native, annual, and weedy species were frequent in the compensation sites, composing on average 17% of the site flora during the final year of monitoring. It is often assumed that early colonizing, ruderal species will wane as restored wetlands age, and several studies have documented such a trend (e.g., Lu et al. 2007; Matthews and Endress 2010; McLane et al. 2012). However, the abundance of more persistent invasive species often increases through time in restored wetlands (Aronson and Galatowitsch 2008; Matthews 2015; Matthews and Spyreas 2010; Moore et al. 1999; Reinartz and Warne 1993; Toth 2010). In our study sites, *Phalaris arundinacea* and *Typha* spp. were the most frequent dominants in 2012. Both are difficult-to-control, clonal perennials that form monodominant stands in emergent wetlands. Increasing dominance by these non-native species contributed to the trend of decreasing compliance that we observed in emergent wetlands, and could foreshadow other compliance problems, including eventual extirpation of planted herbaceous species and declines in floristic quality metrics (Spyreas et al. 2010).

Forested compensation wetlands often failed to comply with standards for the survival of planted trees and shrubs. Most forested compensation wetlands had already failed to comply with these standards by the final year of site monitoring, so we did not observe a decrease in compliance between successive surveys. Forested wetland restoration requires a large initial investment in tree planting, as well as replacement planting in response to mortality. Despite this investment, our results suggest that typical performance standards were not achievable. Failure of tree plantings, often attributed to flood-induced tree mortality, has plagued many wetland restoration and compensation projects (Hill et al. 2013; Krzywicka 2015; Pennington and Walters 2006; Stanturf et al. 2001). In addition to flooding, other potential causes of planting failure include drought, herbivory and competition with naturally colonizing woody or herbaceous species. Native trees naturally recolonize restored forested wetlands, but many of the desired target species, including hard-mast trees like oaks (*Quercus* spp.) and hickories (*Carya* spp.), do not often establish unassisted in reforested wetlands (Battaglia et al. 2008; Shear et al. 1996; Yin et al. 2009). There is a need for additional research to develop restoration techniques to improve the long-term survival of desired planted trees in restored wetlands.

Planting failure was also a frequent problem in restored emergent wetlands in which herbaceous species had been introduced as seed or plugs. Some previous studies have suggested that because wetlands rapidly revegetate even in the absence of planting, and because the species selected for planting are often unsuited to site abiotic conditions, planting may be unnecessary (Mitsch et al. 1998; Moreno-Mateos et al. 2015). However, like desired woody species, desired herbaceous species (e.g. sedges [*Carex* spp.]) may not recolonize restored wetlands unassisted (Galatowitsch and van der Valk 1996). Furthermore, some studies have suggested that if planted species can be established early during restoration, they can inhibit invasive species and maintain long-term species diversity (Mitsch et al. 2012; Petersen et al. 2015; Reinartz and Warne 1993). We suggest that performance standards requiring successful planting of herbaceous species are appropriate for compensation wetlands, but, as with planted trees, our results suggest a need for additional research aimed at improving the success of herbaceous plantings.

Floristic quality assessment indicators have been incorporated in wetland assessment and regulatory programs and have been used, or are proposed for use, in establishing compliance benchmarks for compensation wetlands in some regions of the US (DeBerry et al. 2015). The few sites in our study that had performance standards based on Mean *C* and FQI were often compliant with those standards in the final year of monitoring and in 2012. Floristic quality metrics tend to increase with successional age (Spyreas et al. 2012), and are often greater in natural wetlands than in restored wetlands (Balcombe et al. 2005; Fennessy et al. 2004; Yepsen et al. 2014). However, floristic quality metrics do not invariably increase through time in restorations (DeBerry and Perry 2015; Matthews et al. 2009). In the present study, FQI decreased through time. This finding is not surprising since FQI, which incorporates species richness, is often greater in recently restored wetlands because they tend to be species-rich (Hopple and Craft 2013; Matthews et al. 2009). Floristic quality metrics may be useful for evaluating compensation wetlands, but more research needs to be conducted on their expected behavior through succession (e.g. Spyreas et al. 2012), especially relative to reference wetland conditions, before establishing performance benchmarks for compensation sites.

Almost all performance standards for the study sites were based on measures of vegetation structure and composition, which is consistent with compensatory mitigation performance standards elsewhere in the US (Breaux and Serefiddin 1999; Streever 1999). For example, in an investigation of more than 300 permits from across the country Streever (1999) found that, most commonly, performance standards focused on attributes of the plant community. Despite recommendations to base performance standards on ecological functions in addition to structure (Brooks et al. 2005; NRC 2001; Zedler 1996), performance standards continue to be based largely on measures of vegetation structure.

Landscape Context and Restoration Outcomes

Mean *C* and FQI were greater in compensation wetlands that had been restored adjacent to higher quality natural wetlands. This landscape effect was apparent by the end of site monitoring and was maintained after monitoring had ended. The presence of nearby high quality wetlands could directly benefit compensation sites in two ways. First, nearby wetlands may provide buffers against external environmental stressors such as nutrient and pollutant inputs (Hogan and Walbridge 2007; Houlahan and Findlay 2004). However, this buffering capacity would not necessarily be reflected in the floristic quality of the adjacent wetlands, since nutrient removal may be maximal in highly productive, low diversity wetlands (Doherty and Zedler 2014; Jessop et al. 2015; Weisner and Thiere 2010). Second, nearby high quality wetlands may have provided propagule sources of conservative plant species for the compensation wetlands. Conversely, nearby low quality wetlands may have provided propagule sources of non-conservative or invasive plant species. Previous studies have shown an effect of landscape context on diversity in restorations. For example, Alsfeld et al. (2010) and Holl and Crone (2004) reported that native plant diversity and cover were greater in riparian and wetland restorations where surrounding landscapes had greater cover of forests or wetlands, suggesting an influence of propagule availability on wetland restoration outcomes. Alternatively, the floristic quality of adjacent wetlands may reflect the general condition of the surrounding landscape (Cohen et al. 2004; Lopez and Fennessy 2002; Reiss 2006), and the positive correlation between the floristic quality of compensation wetlands and the quality of adjacent wetlands may be driven by the general condition of the surrounding landscape rather than by direct effects from the adjacent wetlands themselves. Regardless of the driving mechanism, our study demonstrates that the condition of nearby ecosystems is predictive of the long-term condition of a restoration.

Conclusions

Our study reaffirms previous suggestions to extend the length of compensatory mitigation monitoring. Thom (2000), for example, suggested that monitoring should extend past the period of most rapid ecological and biophysical change in wetlands. Stefanik and Mitsch (2012), based on a study of mitigation banks in Ohio, recommended 10 to 15 years of monitoring. Based on the trends observed for emergent wetlands in present study and other studies of compensation wetlands in Illinois (Matthews 2015; Matthews et al. 2009), we also suggest that longer monitoring is necessary in order to detect problems that arise in compensation wetlands beyond the short-term, mandatory assessment phase.

Our finding that floristic quality of compensation wetlands increased with increasing quality of nearby natural wetlands illustrates the importance of siting restoration projects near high quality natural wetlands whenever feasible. Furthermore, we reaffirm calls to establish performance standards based on the characteristics of appropriate natural reference wetlands (Brooks et al. 2005; Matthews et al. 2009) and to set compliance thresholds based on conditions that are realistically attainable in a given landscape setting (Ehrenfeld 2000; Kentula 2000). Nearby or adjacent natural wetlands provide good examples of reasonably achievable restoration outcomes in a particular landscape.

Our study sites were permitted prior to the most recent Mitigation Rule from the Corps and EPA (2008). Although the Mitigation Rule did not unequivocally increase the duration of monitoring, it does potentially address two main findings from our analysis. First, the 2008 Mitigation Rule acknowledges the importance of long-term site management after the monitoring phase. In addition to other changes, the 2008 Mitigation Rule attempts to ensure the sustainability of compensation wetlands by requiring real estate instruments to protect the site and financial instruments for long-term stewardship. Second, the importance of surrounding landscape conditions was explicitly recognized in the 2008 Mitigation Rule, which requires, to the maximum extent practicable, "appropriate siting [of compensatory mitigation projects] to ensure that natural hydrology and landscape context will support long-term sustainability" (Corps and EPA 2008, p. 19679). It remains to be seen whether changes in compensatory mitigation policy and practice will improve the long-term performance of compensation wetlands.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

References

Allen AO, Feddema JJ (1996) Wetland loss and substitution by section 404 permit program in southern California, USA. Environ Manage 20:263–274

Alsfeld AJ, Bowman JL, Deller-Jacobs A (2010) The influence of landscape composition on the biotic community of constructed depressional wetlands. Restor Ecol 18:370–378

Aronson MFJ, Galatowitsch S (2008) Long-term vegetation development of restored prairie pothole wetlands. Wetlands 28:883–895

Balcombe CK, Anderson JT, Fortney RH, Rentch JS, Grafton WN, Kordek WS (2005) A comparison of plant communities in mitigation and reference wetlands in the mid-Appalachians. Wetlands 25:130–142

Battaglia LL, Pritchett DW, Minchin PR (2008) Evaluating dispersal limitation in passive bottomland forest restoration. Restor Ecol 16:417–424

Bourdaghs M, Johnston CA, Regal RR (2006) Properties and performance of the Floristic quality index in Great Lakes coastal wetlands. Wetlands 26:718–735

Breaux A, Serefiddin F (1999) Validity of performance criteria and a tentative model for regulatory use in compensatory wetland mitigation permitting. Environ Manage 24:327–336

Brooks RP, Wardrop DH, Cole CA, Campbell DA (2005) Are we purveyors of wetland homogeneity? A model of degradation and restoration to improve wetland mitigation performance. Ecol Eng 24:331–340

Brown SC, Veneman PLM (2001) Effectiveness of compensatory wetland mitigation in Massachusetts, USA. Wetlands 21:508–518

Cohen MJ, Cartsenn S, Lane CR (2004) Floristic quality indices for biotic assessment of depressional marsh condition in Florida. Ecol Appl 14:784–794

Cole CA, Shafer D (2002) Section 404 wetland mitigation and permit success criteria in Pennsylvania, USA, 1986-1999. Environ Manage 30:508–515

Corps [US Army Corps of Engineers] (2010) Regional supplement to the corps of engineers wetland delineation manual: Midwest Region (Version 2.0). ERDC/EL TR-10-16. US Army Engineer Research and Development Center, Vicksburg, MS

Corps [US Army Corps of Engineers], EPA [US Environmental Protection Agency] (1990) Memorandum of agreement between the Department of the Army and the Environmental Protection Agency: the determination of mitigation under the Clean Water Act section 404(b)(1) guidelines. Signed 6 February 1990, Washington DC

Corps [US Army Corps of Engineers], EPA [US Environmental Protection Agency] (2008) Compensatory mitigation for losses of aquatic resources. Federal Register 73:19594–19705

Dahl TE (2011) Status and trends of wetlands in the conterminous United States 2004 to 2009. US Department of the Interior, US Fish and Wildlife Service, Fisheries and Habitat Conservation, Washington DC

Daubenmire R (1959) A canopy-coverage method of vegetational analysis. Northwest Sci 33:43–64

DeBerry DA, Chamberlain SJ, Matthews JW (2015) Trends in floristic quality assessment for wetland evaluation. Wetland Science and Practice 32:12–22

DeBerry DA, Perry JE (2015) Using the floristic quality concept to assess created and natural wetlands: ecological and management implications. Ecol Indic 53:247–257

Doherty JM, Zedler JB (2014) Dominant graminoids support restoration of productivity but not diversity in urban wetlands. Ecol Eng 65:101–111

Ehrenfeld JG (2000) Evaluating wetlands within an urban context. Ecol Eng 15:253–265

Environmental Laboratory (1987) Corps of Engineers wetlands delineation manual. Technical Report Y-87-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS

EPA [US Environmental Protection Agency] (1980) Guidelines for specification of disposal sites for dredged or fill material. Federal Register 45:85336–85357

Fennessy MS, Mack JJ, Rokosch A, Knapp M, Micacchion M (2004) Integrated wetland assessment program. Part 5: biogeochemical and hydrological investigations of natural and mitigation wetlands. Ohio EPA Technical Report WET/2004-5. Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, OH

Galatowitsch SM, van der Valk AG (1996) The vegetation of restored and natural prairie wetlands. Ecol Appl 6:102–112

Gutrich JJ, Taylor KJ, Fennessy MS (2009) Restoration of vegetation communities of created depressional marshes in Ohio and Colorado (USA): the importance of initial effort for mitigation success. Ecol Eng 35:351–368

Hill T, Kulz E, Munoz B, Dorney JR (2013) Compensatory stream and wetland mitigation in North Carolina: an evaluation of regulatory success. Environ Manage 51:1077–1091

Hogan DM, Walbridge MR (2007) Urbanization and nutrient retention in freshwater riparian wetlands. Ecol Appl 17:1142–1155

Holl KD, Crone EE (2004) Applicability of landscape and island biogeography theory to restoration of riparian understorey plants. J Appl Ecol 41:922–933

Hopple A, Craft C (2013) Managed disturbance enhances biodiversity of restored wetlands in the agricultural Midwest. Ecol Eng 61:505–510

Hornyak MM, Halvorsen KE (2003) Wetland mitigation compliance in the western Upper Peninsula of Michigan. Environ Manage 32:535–540

Hossler K, Bouchard V, Fennessy MS, Frey SD, Anemaet E, Herbert E (2011) No-net-loss not met for nutrient function in freshwater marshes: recommendations for wetland mitigation policies. Ecosphere 2:art82

Houlahan JE, Findlay CS (2004) Estimating the ‘critical’ distance at which adjacent land-use degrades wetland water and sediment quality. Landscape Ecol 19:677–690

Jessop J, Spyreas G, Pociask GE, Benson TJ, Ward MP, Kent AD, Matthews JW (2015) Tradeoffs among ecosystem services in restored wetlands. Biol Conserv 191:341–348

Kentula ME (2000) Perspectives on setting success criteria for wetland restoration. Ecol Eng 15:199–209

Kentula ME, Sifneos JC, Good JW, Rylko M, Kunz K (1992) Trends and patterns in Section 404 permitting requiring compensatory mitigation in Oregon and Washington, USA. Environ Manage 16:109–119

Kozich AT, Halvorsen KE (2012) Compliance with wetland mitigation standards in the Upper Peninsula of Michigan, USA. Environ Manage 50:97–105

Krzywicka AE (2015) Herbaceous and woody plant establishment across hydrologic gradients in bottomland reforestation sites. Masters thesis, University of Illinois

Lavergne S, Molofsky J (2004) Reed canary grass (*Phalaris arundinacea*) as a biological model in the study of plant invasions. Crit Rev Plant Sci 23:415–429

Lopez RD, Fennessy MS (2002) Testing the floristic quality assessment index as an indicator of wetland condition. Ecol Appl 12:487–497

Lu J, Wang H, Wang W, Yin C (2007) Vegetation and soil properties in restored wetlands near Lake Taihu, China. Hydrobiologia 581:151–159

Madsen B, Carroll N, Moore Brands K (2010) State of biodiversity markets report: offset and compensation programs worldwide. http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf

Maron M, Hobbs RJ, Moilanen A, Matthews JW, Christie K, Gardner TA, Keith DA, Lindenmayer DB, McAlpine CA (2012) Faustian bargains? Restoration realities in the context of biodiversity offset policies. Biol Conserv 155:141–148

Matthews JW (2015) Group-based modeling of ecological trajectories in restored wetlands. Ecol Appl 25:481–491

Matthews JW, Endress AG (2008) Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. Environ Manage 41:130–141

Matthews JW, Endress AG (2010) Rate of succession in restored wetlands and the role of site context. Appl Veg Sci 13:346–355

Matthews JW, Spyreas G (2010) Convergence and divergence in plant community trajectories as a framework for monitoring wetland restoration progress. J Appl Ecol 47:1128–1136

Matthews JW, Spyreas G, Endress AG (2009) Trajectories of vegetation-based indicators used to assess wetland restoration progress. Ecol Appl 19:2093–2107

McKenney BA, Kiesecker JM (2010) Policy development for biodiversity offsets: a review of offset frameworks. Environ Manage 45:165–176

McLane CR, Battaglia LL, Gibson DJ, Groninger JW (2012) Succession of exotic and native species assemblages within restored floodplain forests: a test of the parallel dynamics hypothesis. Restor Ecol 20:202–210

Mitsch WJ, Wu X, Nairn RW, Weihe PE, Wang N, Deal R, Boucher CE (1998) Creating and restoring wetlands. BioScience 48:1019–1030

Mitsch WJ, Zhang L, Stefanik KC, Nahlik AM, Anderson CJ, Bernal B, Hernandez M, Song K (2012) Creating wetlands: primary succession, water quality changes, and self-design over 15 years. BioScience 62:237–250

Mohlenbrock RH (2002) Vascular flora of Illinois. Southern Illinois University Press, Carbondale and Edwardsville, IL

Moore HH, Niering WA, Marsicano LJ, Dowdell M (1999) Vegetation change in created emergent wetlands (1988-1996) in Connecticut (USA). Wetl Ecol Manag 7:177–191

Moreno-Mateos D, Meli P, Vara-Rodríguez MI, Aronson J (2015) Ecosystem response to interventions: lessons from restored and created wetland ecosystems. J Appl Ecol 52:1528–1537

Morgan JA, Hough P (2015) Compensatory mitigation performance: the state if the science. Natl Wetl Newsl 37:5–13

Morgan KL, Roberts TH (2003) Characterization of wetland mitigation projects in Tennessee, USA. Wetlands 23:65–69

NRC [National Research Council] (2001) Compensating for wetland losses under the Clean Water Act. National Academy Press, Washington, DC

Palmer MA, Filoso S (2009) Restoration of ecosystem services for environmental markets. Science 325:575–576

Pennington MR, Walters MB (2006) The response of planted trees to vegetation zonation and soil redox potential in created wetlands. Forest Ecol Manag 233:1–10

Peralta AL, Matthews JW, Kent AD (2010) Microbial community structure and denitrification in a wetland mitigation bank. Appl Environ Microb 76:4207–4215

Petersen JE, Brandt EC, Grossman JJ, Allen GA, Benzing DH (2015) A controlled experiment to assess relationships between plant diversity, ecosystem function and planting treatment over a nine year period in constructed freshwater wetlands. Ecol Eng 82:531–541

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2016) nlme: linear and nonlinear mixed effects models. R package version 3.1-128. http://CRAN.R-project.org/package=nlme

R Development Core Team (2016) A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Race MS, Fonseca MS (1996) Fixing compensatory mitigation: what will it take?. Ecol Appl 6:94–101

Reinartz JA, Warne EL (1993) Development of vegetation in small created wetlands in southeastern Wisconsin. Wetlands 13:153–164

Reiss KC (2006) Florida Wetland Condition Index for depressional forested wetlands. Ecol Indic 6:337–352

Reiss KC, Hernandez E, Brown MT (2009) Evaluation of permit success in wetland mitigation banking: a Florida case study. Wetlands 29:907–918

Shear TH, Lent TJ, Fraver S (1996) Comparison of restored and mature bottomland hardwood forests of southwestern Kentucky. Restor Ecol 4:111–123

Shih JG, Finkelstein SA (2008) Range dynamics and invasive tendencies in *Typha latifolia* and *Typha angustifolia* in eastern North America derived from herbarium and pollen records. Wetlands 28:1–16

Sifneos JC, Cake Jr. EW, Kentula ME (1992) Effects of section 404 permitting on freshwater wetlands in Louisiana, Alabama, and Mississippi. Wetlands 12:28–36

Simenstad CA, Reed D, Ford M (2006) When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecol Eng 26:27–39

Spieles DJ, Coneybeer M, Horn J (2006) Community structure and quality after 10 years in two central Ohio mitigation bank wetlands. Environ Manage 38:837–852

Spyreas G, Meiners SJ, Matthews JW, Molano-Flores B (2012) Successional trends in floristic quality. J Appl Ecol 49:339–348

Spyreas G, Wilm BW, Plocher AE, Ketzner DM, Matthews JW, Ellis J, Heske EJ (2010) Biological consequences of invasion by reed canary grass (*Phalaris arundinacea*). Biol Invasions 12:1253–1267

Stanturf JA, Schoenholtz SH, Schweitzer CJ, Shepard JP (2001) Achieving restoration success: myths in bottomland hardwood forests. Restor Ecol 9:189–200

Stefanik KC, Mitsch WJ (2012) Structural and functional vegetation development in created and restored wetland mitigation banks of different ages. Ecol Eng 39:104–112

Streever WJ (1999) Examples of performance standards for wetland creation and restoration in Section 404 permits and an approach to developing performance standards. US Army Engineer Research and Development Center, Vicksburg, MS, TN WRP WG-RS-3.3

Suding KN (2011) Toward an era of restoration in ecology: successes, failures and opportunities ahead. Annu Rev Ecol Evol S 42:465–487

Sudol MF, Ambrose RF (2002) The US Clean Water Act and habitat replacement: evaluation of mitigation sites in Orange County, California, USA. Environ Manage 30:727–734

Swink F, Wilhelm G (1994) Plants of the Chicago region, 4th edn. The Morton Arboretum, Lisle, IL

Taft JB, Wilhelm GS, Ladd DM, Masters LA (1997) Floristic quality assessment for vegetation in Illinois, a method for assessing vegetation integrity. Erigenia 15:3–95

Thom RM (2000) Adaptive management of coastal ecosystem restoration projects. Ecol Eng 15:365–372

Toth LA (2010) Restoration response of relict broadleaf marshes to increased water depths. Wetlands 30:263–274

Weisner SEB, Thiere G (2010) Effects of vegetation state on biodiversity and nitrogen retention in created wetlands: a test of the biodiversity-ecosystem functioning hypothesis. Freshwater Biol 55:387–396

Wilson RF, Mitsch MJ (1996) Functional assessment of five wetlands constructed to mitigate wetland loss in Ohio, USA. Wetlands 16:436–451

Yepsen M, Baldwin AH, Whigham DF, McFarland E, LaForgia M, Lang M (2014) Agricultural wetland restorations on the USA Atlantic Coastal Plain achieve diverse native wetland plant communities but differ from natural wetlands. Agr Ecosyst Environ 197:11–20

Yin Y, Wu Y, Bartell SM, Cosgriff R (2009) Patterns of forest succession and impacts of flood in the Upper Mississippi River floodplain ecosystem. Ecol Complex 6:463–472

Zedler JB (1996) Ecological issues in wetland mitigation: an introduction to the forum. Ecol Appl 6:33–37

Zedler JB, Callaway JC (1999) Tracking wetland restoration: do mitigation sites follow desired trajectories?. Restor Ecol 7:69–73