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A comparison of created and natural wetlands in Pennsylvania, USA

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Abstract

Recent research suggests that created wetlands do not look, or function, like the natural systems they are intended to replace. Proper planning, construction, and the introduction of appropriate biotic material should initiate natural processes which continue indefinitely in a successful wetland creation project, with minimal human input. To determine if differences existed between created and natural wetlands, we compared soil matrix chroma, organic matter content, rock fragment content, bulk density, particle size distribution, vegetation species richness, total plant cover, and average wetland indicator status in created (n = 12) and natural (n = 14) wetlands in Pennsylvania (USA). Created wetlands ranged in age from two to 18 years. Soils in created wetlands had less organic matter content, greater bulk densities, higher matrix chroma, and more rock fragments than reference wetlands. Soils in reference wetlands had clay loam textures with high silt content, while sandy clay loam textures predominated in the created sites. Vegetation species richness and total cover were both greater in natural reference wetlands. Vegetation in created wetlands included a greater proportion of upland species than found in the reference wetlands. There were significant differences in soils and vegetation characteristics between younger and older created wetlands, though we could not say older created sites were trending towards the reference wetland condition. Updated site selection practices, more careful consideration of monitoring period lengths, and, especially, a stronger effort to recreate wetland types native to the region should result in increased similarity between created and natural wetlands.

Introduction

In the United States, development within a wetland often requires a permit and subsequent compensatory mitigation of impacts. One compensatory mitigation option is the creation of wetlands where none existed (as compared with restoration of damaged wetlands). Regulatory agencies have agreed that compensatory mitigation should strive toward functional replacement of lost wetlands, rather than just areal replacement (Memorandum of Understanding, February 7, 1990). Galatowitsch and van der Valk (1994) stated that "... how closely restored wetlands resemble and function like natural wetlands is the definitive test of their success." Physical resemblance may or may not lead to functional replacement. It is relatively simple to return vegetation to a site without returning function. Throughout this paper, the term 'success' refers to functional replacement of lost wetlands, while 'failure' refers to the absence of functional replacement of lost wetlands. Determining just what constitutes successful replacement of created wetland projects depends in large part on an understanding of the processes at work in the created ecosystem.

Proper planning, construction, and the introduction of appropriate biotic materials should initiate natural ecological processes which continue indefinitely in a successful project. However, Erwin (1991) found 60% of a set of 40 compensatory mitigation projects in Florida were either incomplete or failures. Race (1985) examined 11 wetland mitigation projects in San Francisco Bay and stated that "it is debatable whether any sites . . . can be described as complete, active, or successful." Reinartz and Warne (1993) pointed out that "there has been very little short-term, and almost no long-term, monitoring" of the hundreds of created and restored inland freshwater wetlands built over the last 50 years. Mitsch and Wilson (1996) noted many other authors who had similar findings, and concluded that "there is much room for improvement in the building of wetlands."

In all situations, monitoring of the created wetland is essential to ascertain whether the artificial ecosystem actually resembles the lost natural one. The criteria used for determining success of compensatory mitigation wetlands are a topic of ongoing debate (e.g. Cole, 1998), but biotic community structure is often taken as a surrogate for ecosystem function (Kentula et al., 1992). Community structure is usually determined through analysis of a few features, such as vegetation (Brooks, 1989; Jarman et al., 1991; Atkinson et al., 1993; Mitsch and Wilson, 1996) or invertebrate community structure (Streever et al. 1996).

Monitoring of created wetlands is sporadic at best (Mager, 1990; Holland and Kentula 1992). Even when field monitoring is stipulated in permits, monitoring times are usually short and are inadequate for assessing present success or failure, much less future site conditions (Mitsch and Wilson, 1996). In general, key wetland characteristics, especially hydric soil indicators, that are strongly evident in natural sites are lacking or nonexistent in created wetlands (Erwin, 1991; Bishel-Machung et al., 1996). This may be due to the relative 'ecological immaturity' of the created sites at the time of monitoring (Reppert, 1992).

It is important to assess created wetlands relative to the correct set of local or regional natural reference wetlands. If suitable reference wetlands are not found near the created sites, this becomes a first clue as to whether the proposed mitigation wetland has been properly designed. In fact, the created wetland type may not belong in that location on the landscape. In such a case, it becomes necessary to gather reference wetland information from a broader area for evaluation of created wetlands.

The objectives of this study were to: (1) compare soils and vegetation of created wetlands and natural reference wetlands in Pennsylvania; and (2) determine if, with increasing age, soils and vegetation in created wetlands more closely resemble those of natural wetlands. The null hypotheses were: (1) soil characteristics and vegetation community structure are the same in created and reference wetlands; and (2) soil characteristics and vegetation community structure of created wetlands do not change over time.

Table 1. Areas and sources for created wetlands in Pennsylvania (PennDOT, Pennsylvania Department of Transportation; PIP, Peterson Industrial Park; Mining, surface coal mining).

Site name	Year created	Size (ha)	Source
220A	1993	3.90	PennDOT
Peterson Industrial Park A	1992	0.55	PIP
Peterson Industrial Park B	1992	0.37	PIP
Mt. Jewett	1991	0.26	PennDOT
Tipton	1991	5.26	PIP
Snowshoe Rest Area	1990	0.72	PennDOT
Mt. Eagle	late 1980's	0.28	PennDOT
Four Ponds	1980	0.68	Mining
Stott A	late 1970's	0.19	Mining
Stott B	late 1970's	0.30	Mining
Sproul Interchange	late 1970's	0.43	PennDOT
Duncansville	late 1970's	0.31	PennDOT

Methods

Study area

Twelve wetland creation projects were chosen from a pool of compensatory mitigation wetlands in central Pennsylvania (Figure 1, Table 1). Projects were planned to mitigate wetland losses due to highway construction, mining, or industrial land uses, and spanned a range of ages from 2 to approximately 18 years. Created wetland projects ranged from 0.19–0.26 ha in area (Table 1). All of the sites were classified as palustrine emergent (PEM – Cowardin et al., 1979), typically with some area of open water.

Fourteen natural wetlands were chosen to serve as reference sites (Figure 1, Table 2). Reference wetlands were chosen to consist of typical PEM's for Pennsylvania, and included sites that ranged from disturbed to pristine (Brinson and Rheinhardt, 1996). Reference wetlands ranged from 0.13–2.08 ha in area (Table 2).

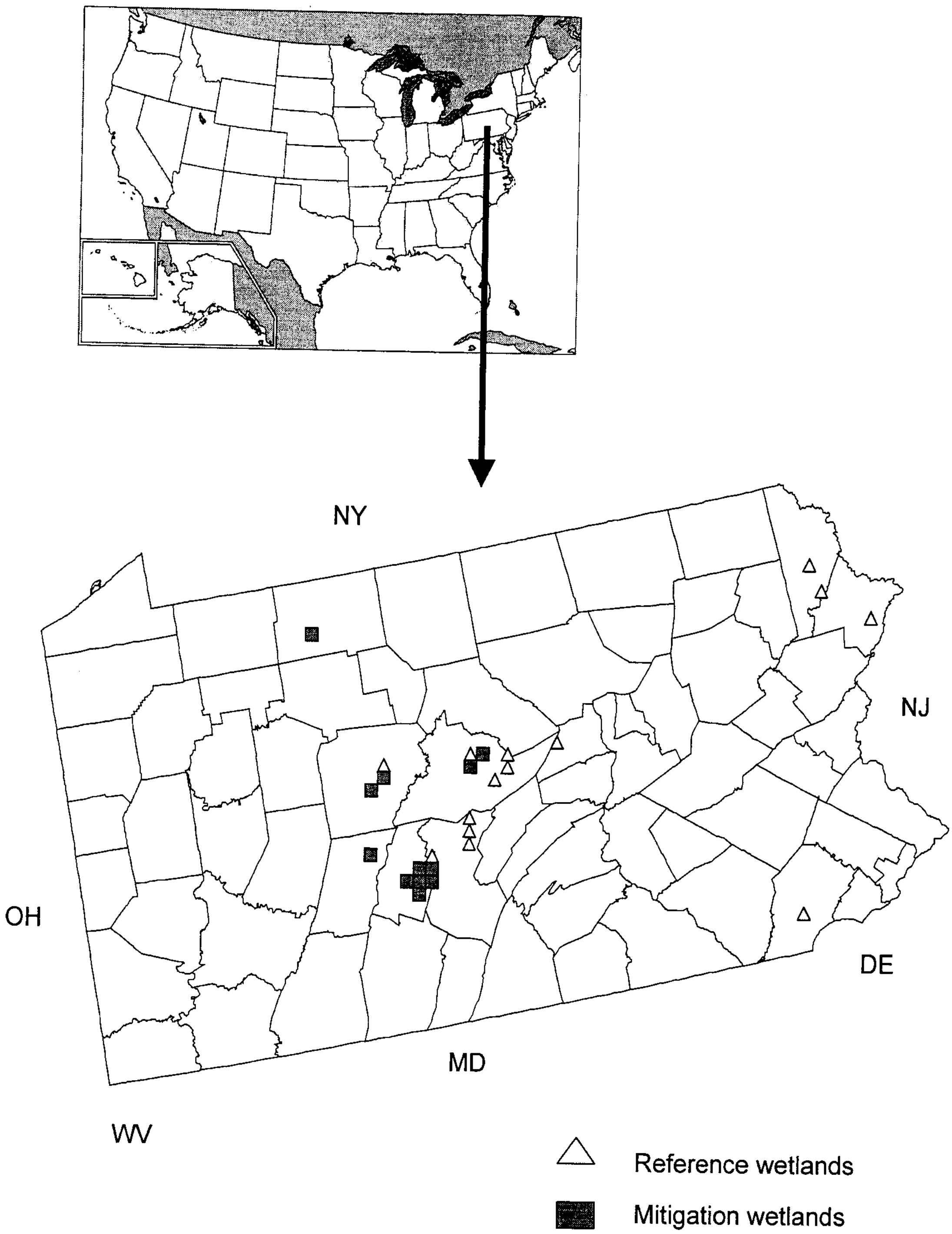

Figure 1. Map of Pennsylvania with locations of mitigation and reference wetlands.

Table 2. Areas and types of natural reference wetlands in Pennsylvania (PEM, palustrine emergent; PSS, palustrine scrub/shrub; POW, palustrine open water).

Site name	Size (ha)	Dominant type
Bald Eagle State Park-PEM	2.08	PEM
Canoe Creek State Park	0.13	PEM
Mothersbaugh Swamp	2.06	PEM
Clark's Trail	0.39	PEM/PSS
Central PA Lumber	1.12	PEM
Old Greentown Road	1.80	PEM
Lakeville Hunt Club	1.20	PEM/PSS
Marsh Creek	1.30	PEM
Windy Hill Farms	2.03	PEM
Cedar Run	0.29	PEM/PSS
Fravel	0.23	PEM/PSS
Stone Valley Recreation Area	0.36	PEM/POW
Davis	0.44	PEM
Decker Pond	0.84	PEM/POW

We chose to categorize both created and natural wetlands according to Cowardin et al. (1979) rather than by hydrogeomorphology (e.g., Cole et al., 1997). Recent work (Brooks et al., 1996; Cole et al., 1998; Cole and Brooks, 2000) indicates that created wetlands in Pennsylvania do not fit into any recognized HGM subclass.

Site survey and field sampling

Created wetlands were surveyed in late April and early May 1995 using a standard protocol (Brooks et al., 1996). Each site was mapped for elevation and distance measurements on a 20-m grid. Soil and vegetation sampling took place in early June and mid-August 1995 and occurred on the intersections of grid lines; sample plots were flagged and labeled according to transect and baseline number.

Sampling and analysis

At each plot within the created wetland population, soils were examined at 5- and 20-cm depths (Bishel-Machung et al., 1996) for matrix chroma using a Munsell color chart. Soil chroma is a useful indicator of soils formed under reducing conditions and, in general, chroma values less than 2 are indicative of hydric soils (Freeland 1999). Soil samples were removed for laboratory analysis of rock fragment content, organic matter content, particle size distribution, and bulk density. The ratio of soil samples to total plots within a site was 20–25%, and soil sample plots were chosen such that they encompassed a range of topographic elevations within each site. More samples were collected at larger sites, with the number of samples per site ranging between 2 and 16. Approximately half of the sample sites used in this study were also those used in Bishel-Machung et al. (1996), but separate samples were collected.

All soil samples were air-dried and passed through a No. 10 sieve (2-mm mesh). The fraction of soil samples >2 mm was used to determine percent rock fragments by weight for each sample. Particle size analysis (PSA) was performed on 50 g of each unaltered air-dried sample to determine soil texture (the hydrometer method, Bouyoucos, 1962). Soil bulk density (g/cm^3) was determined by weight using oven drying of intact soil cores (726 cm^3) (Blake and Hartge, 1986).Organic matter content was determined using loss of weight on ignition (LOI) at 450 °C (Storer, 1984).

Vegetation species richness was recorded at each intersection of the 20-m grid by making a species list for a 5-m radius circle surrounding the gridpoint. Standard plant identification keys were used (Hotchkiss, 1972; Newcomb, 1977; Brown, 1979; Knobel, 1980). Species composition and abundance at each intersection of the 20-m grid were determined by randomly tossing one 0.25-m^2 quadrat frame within the same 5-m radius circle surrounding the gridpoint, and recording up to five dominant herbaceous species and their percentage cover within the frame ('dominant' refers to at least 20% cover). Average wetland indicator status (WIS, Wentworth et al., 1988) was determined for each plot using dominant species found within the frame and their respective percentage cover. Plants that are found almost entirely in wetlands have a WIS of 1 and those found almost entirely in uplands score a 5, with gradations in between.

We did not attempt to develop a formal description of the plant community at any wetland. We did functionally classify species according to methods outlined by Boutin and Keddy (1993). Functional groups of plants are based upon growth form, habitat use, and responses to environmental stress. There are three main groups: ruderals, interstitial perennials, and matrix species. Ruderals either die after one year (obligates) or produce shoots from the stem base (facultative). These species have high photosynthetic area and a low root/shoot ratio. Interstitial perennials do not flower during their first year, have clumped growth forms and shallow root systems. The three subgroups (reed, clonal, and tussock) reflect their growth form. The matrix group has clonal dominants (spreading by rhizomes) and clonal stress-tolerators (able to withstand infertile environments).

Data analysis

Nonparametric methods were used for statistical analyses because of small sample sizes and nonnormal distributions. As such, we report median values rather than means. All analyses were conducted using Minitab statistical software (Minitab, Inc., 1995). The created and reference populations were compared using the Mann-Whitney two-sample test. Soil and vegetation variables were compared among created wetlands using the Kruskal-Wallis H test, and were also compared among younger and older created wetlands using Mann-Whitney. If differences were detected, we used the Bonferroni test (multiple comparisons) to ascertain where differences lay. To assess the effects of age on results from the created wetlands themselves, these sites were classified as generally younger (<10 yr) and generally older (>10 yr). Differences were considered significant at $p < 0.05$.

Table 3. Summary of median values of created versus natural reference wetlands in Pennsylvania. Items with the same letter are not significantly different. Results are presented as medians and, as such, percentages of sand, silt, and clay may not sum to 100%.

Variable	Created wetlands	Reference wetlands
5 cm soil characteristics:		
Organic matter (%)	4.8[a]	11.5[b]
Soil chroma	2.0[a]	1.0[b]
Sand content (%)	52.1[a]	23.7[b]
Silt content (%)	20.0[a]	45.2[b]
Clay content (%)	22.0[a]	30.0[b]
Rock fragments (%)	18.3[a]	0.0[b]
20 cm soil characteristics:		
Organic matter (%)	2.8[a]	7.2[b]
Soil chroma	2.0[a]	1.0[b]
Sand content (%)	54.3[a]	21.9[b]
Silt content (%)	15.0[a]	39.5[b]
Clay content (%)	30.1[a]	31.4[a]
Rock fragments (%)	23.3[a]	0.0[b]
Soil bulk density (g/cm^3)	1.2[a]	0.6[b]
Species richness	5.0[a]	10.0[b]
Total cover (%)	75.0[a]	95.0[b]
Wetland indicator status	2.4[a]	1.0[b]

Results and discussion

Soils

Most soil characteristics differed between created and reference wetlands (Table 3). Only soil clay content at 20-cm depths in created wetlands was similar to natural reference wetlands. Reference wetland soils had significantly higher organic matter content than created wetlands. Soil chroma values at 5- and 20-cm depths were higher in created sites than in reference sites. There were significantly more rock fragments in created wetlands than in natural reference wetlands. Median bulk density for created wetlands was twice as high as that of reference wetlands (Table 3).

Many of these created wetland soils are upland remnants and we should expect to see dissimilarities between those depths, especially with time. Soil textures in created sites had a high percentage of sand, which is typical of wetlands developed from excavated upland substrates (Bishel, 1994). As such, created wetland soils were classified as sandy clay loams at both 5- and 20-cm depths. Reference sites had much less sand and more silt and were classified as clay loams at both 5- and 20-cm depths (Figure 2).

The slightly higher silt levels we found at 5 cm may be due to some accretion. This is to be expected because silts and organic matter accrete at the soil surface. This process is typical of natural wetlands, but increases in the organic fraction are not often noted in created wetlands due to the long time periods required for organic soil development (Bishel-Machung et al., 1996). Soil organic matter is a frequent parameter used to assess soil development and is critical for plant community establishment in created wetlands (Stauffer and Brooks, 1997). Soil organic matter has not been shown to develop through time for wetlands in the Ridge and Valley Province. Odum (1969) noted that increases in organic matter content are characteristic of developing ecosystems approaching ecological 'maturity,' but after more than 10 yr, the created wetlands appear not to be accumulating meaningful amounts of soil organic matter.

In another study on Pennsylvania wetlands, Bishel-Machung et al. (1996) found that clay content at 20 cm in created wetlands was significantly lower than in reference wetlands. However, in contrast, our study found no significant difference in clay content (per-

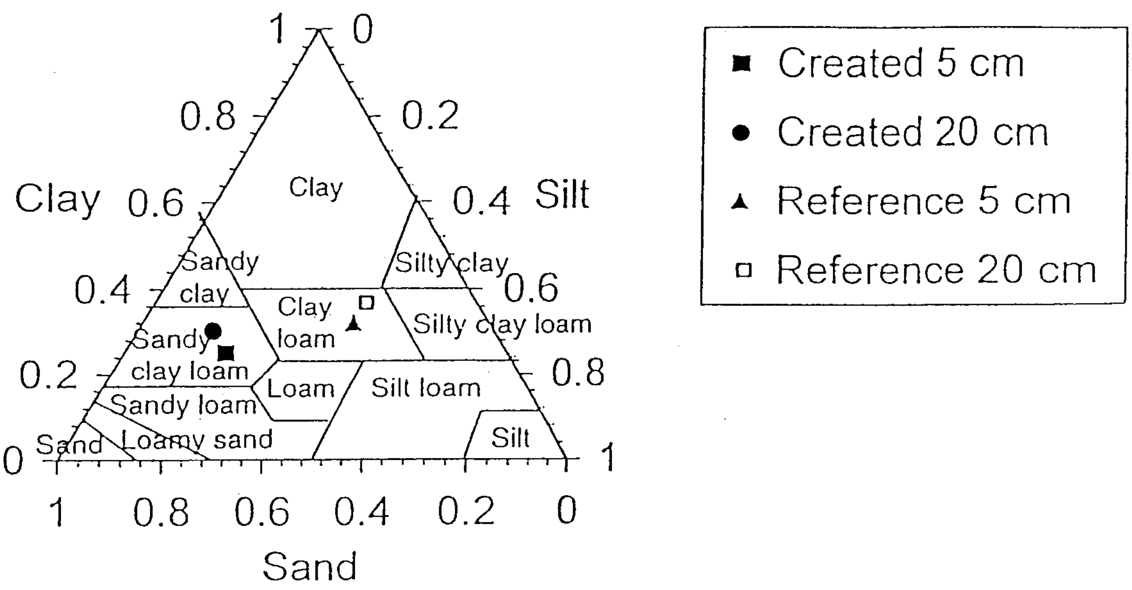

Figure 2. Textural triangle showing median percent sand, silt and clay for created and natural reference wetlands at 5 and 20 cm.

haps due to different sets of reference wetlands for comparison). Higher amounts of clay at this depth in natural wetlands are typical of highly weathered soils, but are usually uncommon in compensatory mitigation sites where excavation of upper soil layers to reach the water table often results in larger soil particles at a 20-cm depth (Buol, 1990).

Bulk density was twice as high in created wetlands than in reference wetlands, probably due both to high sand content and to compaction at the surface from construction (Brooks, 1993). Bulk densities were high even in the oldest created wetlands, indicating that soil compaction is not lessening significantly over time, even though organic matter is somewhat greater in older created wetlands.

Plant community

Plant species richness and total vegetative cover were lower in created wetlands than in reference wetlands (Table 3). Average wetland indicator status was higher in created than in natural reference wetlands, denoting a greater proportion of upland plant species. Species richness of plots in the younger created sites was double that of the older sites, and all created sites had lower species richness than the reference wetlands.

Size of a particular wetland may impact species richness a great deal. However, only two of the newer created wetlands (Route 220, Tipton) were appreciably larger than the older sites (Table 1). The Route 220 wetland was dominated by *Phalaris arundinacea* and showed little plant diversity. In addition, fully half of the reference wetlands (7 of 14) were of comparable size to the created wetlands (Table 2). As a result, size may not have been a significant factor in determining species richness.

Differences in species richness within and between groups may also be due to contextual influences, such as the distance to nearby seed sources (Jarman et al., 1991). Most of the created wetlands were established in uplands, with few nearby wetland seed sources. Only one was built directly adjacent to an existing wetland. The lack of incoming volunteer species (except for cattail (*Typha latifolia*) which was prevalent on all project sites), may account for the low number of species. Conversely, low species richness may also be due to invasion of cattail, which can outcompete many other species due to its aggressive reproductive strategies (Mitsch and Gosselink, 1993).

Plant communities in created wetlands were fairly similar to each other in terms of functional group distribution and their underlying life history characteristics. Half of the created wetlands (mostly younger projects) were dominated by facultative annual species such as *Impatiens capensis* and *Bidens frondosa*. These are highly competitive, early successional species with rapid growth, high photosynthetic area, low root/shoot ratio, and small mature size. Most of the remaining created wetlands were dominated by clonal species such as *Typha latifolia*. *Typha* is tall at maturity, with low photosynthetic area, and a deep, clonally-spreading root system. It often forms vegetative monocultures (Boutin and Keddy, 1993). Clonal species were most prevalent on the three oldest project sites.

Plant communities in created wetlands were different than those in reference wetlands. Created wetlands were dominated by facultative annual species, while reference wetlands were dominated by clonal species. Dominant matrix species such as *Typha latifolia* were found at similar coverage levels in both created and reference wetlands. However, the low species richness encountered on the project wetlands made the presence of large patches of dominant matrix species more noteworthy.

Total cover requirements in compensatory mitigation projects are often set at 75% or 85% for the first two years. Reference sites had median plant cover per plot of 95%. As a group, the created wetlands had median total cover of 75%. Three of the 12 created wetlands had median total cover of 85% or greater. It would appear that permit requirements are being met, even if plant community composition was different from the reference wetlands.

Vegetation features were significantly different between younger and older created wetlands, and natural reference wetlands. Species richness was 6 in younger created sites, 3 in older sites, and 10 in reference sites. Similarly, total cover was higher in reference wetlands (95%) than in younger (75%) or older (65%) created wetlands (Table 4).

Table 4. Summary of median values of created versus natural reference wetlands, with created wetlands grouped into <10 yr (n = 7) and >10 yr (n = 5). Items with the same letter are not significantly different. Results are presented as medians and, as such, percentages of sand, silt, and clay may not sum to 100%.

Variable	Created wetlands <10 yr	Created wetlands >10 yr	Reference wetlands
5 cm soil characteristics:			
Organic matter (%)	4.8[a]	5.8[b]	11.5[c]
Soil chroma	2.0[a]	2.0[a]	1.0[b]
Sand content (%)	55.0[a]	35.0[b]	23.7[b]
Silt content (%)	20.0[a]	20.0[a]	45.2[b]
Clay content (%)	26.4[a]	48.2[b]	22.0[c]
Rock fragments (%)	15.8[a]	19.6[a]	0.0[b]
20 cm soil characteristics:			
Organic matter (%)	2.2[a]	5.5[b]	7.2[c]
Soil chroma	2.0[a]	3.0[a]	1.0[b]
Sand content (%)	55.0[a]	48.7[b]	21.9[c]
Silt content (%)	15.0[a]	15.0[a]	39.5[b]
Clay content (%)	28.4[a]	50.0[b]	31.4[a]
Rock fragments (%)	17.4[a]	32.4[a]	0.0[b]
Soil bulk density (g/cm^3)	1.3[a]	1.1[a]	0.6[b]
Species richness	6.0[a]	3.0[b]	10.0[c]
Total cover (%)	75.0[a]	65.0[b]	95.0[c]
Wetland indicator status	2.7[a]	1.0[b]	1.0[b]

Age, soil and vegetation in created wetlands

All soils and vegetation characteristics, except rock fragment content (5 cm: H = 7.2, df = 7, $p = 0.4$, and 20 cm: H = 8.8, df = 8, $p = 0.4$) and soil bulk density (H = 10.3, df = 11, $p = 0.5$), were significantly different among the created wetlands themselves. Thus, the created wetlands themselves were quite variable. To determine if this variability was due to age, created wetlands were then classified as generally younger (<10 yr) and generally older (>10 yr). Some soil characteristics differed between younger and older created sites (Table 4). Soil organic matter content at 5 and 20 cm, clay content at 5 and 20 cm, and sand content at 5 and 20 cm were significantly different between younger and older created wetlands (Table 4). However, only sand content and organic matter exhibited trends that could be construed as created wetlands becoming more similar to the reference wetlands. Sand content was reduced in the older age group towards the reference condition and organic matter was greater in the older age group, also towards reference conditions.

Other characteristics (soil chroma at 5- and 20-cm depths, silt content at 5- and 20-cm depths, and bulk density) showed no significant differences between younger versus older created wetlands. There were no significant differences between young created wetlands and natural reference wetlands for clay content at 20 cm, and between older created wetlands and reference wetlands for sand content at 5 cm (Table 4).

Conclusions

Our null hypotheses were: (1) soils and vegetation are not different in created and reference wetlands; and (2) soils and vegetation of created wetlands do not change over time. Based on the results of this study, only the first hypothesis could be rejected. We could not reject the second hypothesis as some characteristics (sand content and soil organic matter) did appear to change slightly over time towards the reference condition.

The created wetlands were probably jurisdictional wetlands (as defined in the United States by the USACE (1987)). Soil matrix chroma and wetland indicator status (WIS) are two commonly used properties for characterizing the boundaries of a wetland (Segelquist et al., 1990; Atkinson et al., 1993). While these two parameters were significantly different between created and natural reference sites, it is noteworthy that two of the 12 created wetlands had soil matrix chroma medians that were within the hydric soils range (<2), and that seven of the created wetlands had wetland indicator status values sufficient to describe their vegetative communities as 'hydrophytic' (i.e., WIS<3.0).

Project age (i.e., a lack of ecological maturity) is likely a reason for the obvious differences between created and natural wetlands. Few physical characteristics of older created wetlands, such as soil texture and organic matter content, were similar to levels found in natural reference wetlands. The amount of time needed for the development of wetland function is not known; however, this uncertainty serves to further emphasize the problems of short or nonexistent monitoring periods. Mitsch and Wilson (1996) and Cole (1999) note that wetland ecologists have begun to emphasize the need for long-term monitoring to accurately document success or failure of projects.

If created wetlands are to be 'in-kind', then we should be able to compare them with local natural wetlands of the same type. If created wetlands are 'out-of-kind', then we should be able to compare them with local natural wetlands found in the same position on the landscape. Critics often argue that certain aspects of created wetlands (e.g., plant communities, soils) cannot possibly be similar to natural wetlands within the typical monitoring time frame ($\sim$5 years). There simply has not been enough time and, therefore, we are comparing 'apples with oranges'. However, we have no other information upon which to pronounce 'success' at the end of a monitoring period. If these traits are not equivalent to natural reference counterparts, then we cannot be assured that we are achieving 'no-net-loss' of wetlands, either 'in-kind' or 'out-of-kind'. In any event, we should be able to examine these characteristics after a period of time subsequent to permit release to assess their performance relative to reference wetlands. This appraisal will lend itself to a more in-depth assessment of 'success'. Other physical traits (e.g., morphometry, hydrology) should be immediately comparable as these reflect design choices. It is these initial physical characteristics that set the tone for all subsequent successional development within a compensatory mitigation wetland. These characteristics, therefore, should be correct and present from the onset of monitoring.

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