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Plant community development as affected by initial planting richness in created mesocosm wetlands

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ABSTRACT

The gain or loss of plant species may alter the development of structural and functional attributes critical to developing or restoring ecosystem services in created mitigation wetlands. A three-year study was conducted in created mesocosm wetlands to determine the role of initial planting richness (IPR) in vegetation community development using five species of plants common to natural and created wetlands in the Virginia Piedmont. The mesocosms were naturally colonized by volunteer species after planting the same as in real-world mitigation wetlands created in the region. At the end of each growing season, all species present were identified, and species richness (S) and cover percentages (i.e., percent total, planted and volunteer species) were measured. Indices for diversity (Shannon–Weiner H') and prevalence (PI) were calculated. After establishment of planted rhizomes, hydrology was maintained solely by precipitation. However, unintended leaking in six mesocosms in the beginning of the study created two distinctively different hydrologic conditions (i.e., wet vs. dry conditions) that were factored into the final data analysis. Both richness (S) and biodiversity (H') varied significantly with initial planting richness (IPR). Differences in these two attributes were mainly due to differences between monotypic mesocosms (IPR = 1) and those with the greatest number of species initially planted (IPR = 5). Hydrologic conditions impacted some of the plant community characteristics, including total percent cover being higher in one year and PI being lower both in “wet” conditions. The mesocosms were becoming typical of wetlands with more hydrophytes present over the course of the study. The outcome of the study showed that the mesocosm wetlands were following a similar pattern found in vegetation community development trajectory of newly created mitigation wetlands. The study showed the positive effect of initial planting richness on species richness and diversity in the early development of plant community. Our findings also reinforce the importance of maintaining adequate hydrologic conditions for the early development of vegetation community in created mitigation wetlands.

1. Introduction

The role of species richness on ecosystem functioning has emerged as a key research topic in ecology during the past decade (Hooper and Vitousek, 1997; Tilman et al., 1997; Engelhardt and Ritchie, 2001; Kinzig et al., 2006; Loreau et al., 2002; Hooper et al., 2005). A number of previous studies indicated that ecosystem functions, such as primary productivity, are often significantly influenced by the assemblage of plant species present in a community (Hooper et al., 2005). A positive relationship between plant species richness and a variety of ecosystem functions, including carbon and nitrogen accumulation and net primary productivity (NPP), has been observed (Hooper and Vitousek, 1997; Tilman et al., 1997; Schläpfer and Schmid, 1999; Engelhardt and Ritchie, 2001; Kinzig et al., 2006; Loreau et al., 2002; Hooper et al., 2005; Lawrence and Zedler, 2013). Most studies on the role of plant richness are based on grassland on various ecosystem structure and functions (Collins and Adams, 1983; Cardinale et al., 2006; Balvanera et al., 2006; Isbell et al., 2011). However, there is a lack of information on the relationship between species richness and ecosystem development in created wetlands. Created wetlands are wetlands constructed in an area where a wetland did not previously exist.

Legally, and ecologically, wetland mitigation requires the development and establishment of wetland vegetation communities (USACE, 1987; NRC, 2001; Spieles, 2005). Planting, the deliberate placing of wetland species, is an important part of wetland mitigation since vegetation development is the most

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commonly used metric for determining mitigation success. However, vegetation establishment is most often achieved by intentional seeding or planting of wetland species along with natural recruitment of volunteer species from adjacent communities. To date, many created mitigation wetlands have developed lower species richness and total plant cover and had fewer native species volunteer compared to natural wetlands (Balcombe et al., 2005; Gutrich et al., 2009). Currently there is no consideration of planting diversity in mitigation wetlands when created, nor is planting diversity mandated for vegetation management. Lack of these considerations may lead to a monotypic development of wetland vegetation community ending in a mitigation failure (Galatowitsch and van der Valk, 1996; Zedler and Callaway, 1999; Farrer and Goldberg, 2009).

Few studies have been conducted specifically on the impact of IPR on species richness, species diversity, or vegetation indices of plant community development in created wetlands. In a whole-system experiment, Mitsch et al. (2005) found that a planted created wetland showed more diversity and greater cover but less productivity than a non-planted wetland after 10 years. In 1- to 3-year old depressional created wetlands in Wisconsin, Reinartz and Warne (1993) found higher species diversity in mitigation sites that had been intentionally seeded with wetland species at time of creation (i.e., construction) than in unseeded sites, or ones left barren. Bouchard et al. (2007) found that increasing the number of functional groups planted increased the development of plant root biomass. Other studies have found that plant community development in created mitigation wetlands is closely related with construction elements such as microtopography (Bruland and Richardson, 2005; Moser et al., 2007), altered hydrology (Wilcox, 1995), and soil physicochemical conditions (Dee and Ahn, 2012). These elements, in turn, also affect ecosystem functions such as enhanced carbon storage (Wolf et al., 2011a), nitrogen cycling and removal (Wolf et al., 2011b), soil hydraulic properties (Petru et al., 2013), and wetland microbial communities (Ahn and Peralta, 2009, 2012). Establishment of wetland vegetation during the five years immediately following creation of permitted compensatory mitigation projects is one of the performance standards required by Section 404 of the Clean Water Act and Sections 9 and 10 of the Rivers and Harbor Act [§33CFR 332.6(b)] (Votteler and Muir, 2002; Connolly et al., 2005).

In the present study, carried out in outdoor mesocosms over three growing seasons, we investigated vegetation establishment as affected by IPR. We monitored several structural attributes of vegetation and investigated how the development of these attributes was affected by initial planting richness and hydrologic conditions that are often realistic in large-scale mitigation wetlands created in the Virginia Piedmont. Our main hypothesis was that the community diversity of vegetation in created mesocosm wetlands would be positively impacted by the initial planting richness.

2. Methods

2.1. Mesocosm description and planting

Our experiment was carried out under field conditions for three growing seasons (2010–2012) in a 0.1 ha research site (38°50′3.46″N, 77°19′14.17″W). The site is on a 100 year floodplain adjacent to a stormwater management pond on the Fairfax campus of George Mason University. Twenty 568 l ($0.99\,\mathrm{m}^2 \times 0.64\,\mathrm{m}$) elliptically-shaped polyethylene tubs manufactured by Rubbermaid® and placed in this site were used as mesocosms, small outdoor experiment units that are often used to simulate a large-scale wetland (Bloesch, 1988). The mesocosms were buried in the ground to insulate roots against possible freezing (Fig. 1a). Standpipes connected to each mesocosm that rose aboveground allowed visual monitoring of the water level (Fig. 1b). Each mesocosm was filled with 10 cm of river pea gravel on the bottom, topped by 20 cm of commercial garden topsoil, the same kind used in local mitigation wetlands during their construction. The soil was allowed to settle in the mesocosms for several days prior to planting.

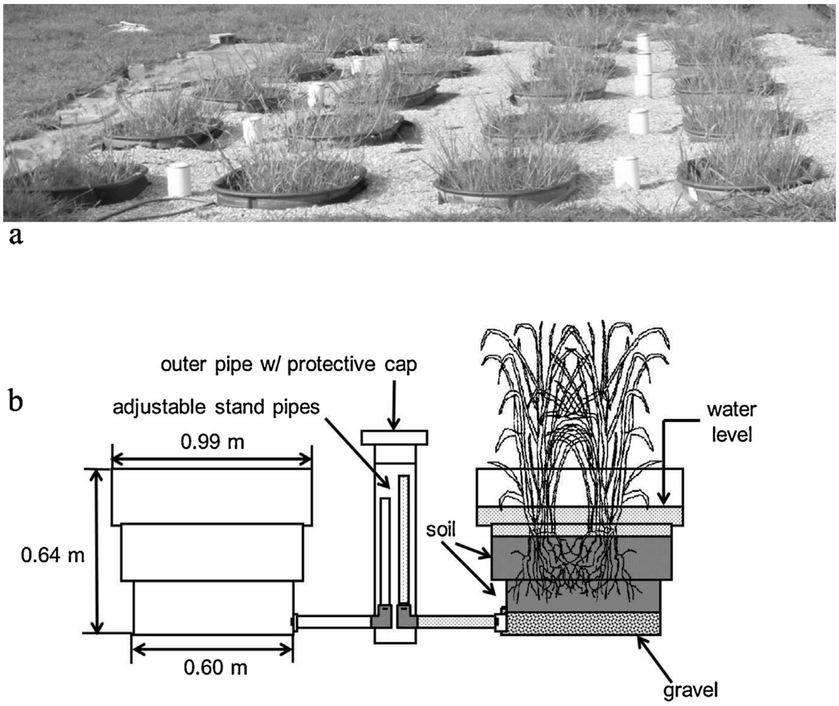

Fig. 1. (a) Study site at the Wetland Research Compound at George Mason University, Fairfax, VA, illustrating the layout and stand-pipe set-ups for the mesocosms used in this study. (b) Mesocosms with stand-pipe set-up allowing monitoring of the water levels in each mesocosm.

Soil plugs (10 cm^2) containing rhizomes of five wetland plant species were obtained from Environmental Concern Inc. (St. Michaels, MD). Species planted were *Asclepias incarnata* L. (swamp milkweed), *Carex vulpinoidea* Michx. (fox sedge), *Juncus effusus* L. (soft bulrush), *Scirpus atrovirens* Willd. (green bulrush), and *Scirpus cyperinus* (L.) Kunth (woolgrass). These native wetland species have commonly been seeded in local wetland mitigation projects (Moser et al., 2007, 2009; Ahn and Peralta, 2009; Wolf et al., 2011a,b; Petru et al., 2013), or found in several mitigation banks in the northern Virginia Piedmont as a result of colonization (Dee and Ahn, 2012). In May 2010, eight mesocosms were planted monotypically with each of the five selected species. Four mesocosm were planted with a combination of two species. Four mesocosms were planted with a random mix of three species and another four mesocosms were planted with all five species. The planting density was four plugs per mesocosm other than the four mesocosms with highest planting richness (i.e., one plug for each of five species). The authors chose this planting density per the surface area of the mesocosms based on a previous experiment with the same type of wetland mesocosms (Ahn and Mitsch, 2002).

Plugs were spaced equally apart along the central length of each mesocosm, oriented north to south to maximize sunlight exposure. The rhizomes were then pressed into the moist topsoil and buried to a depth of 3 cm. Plants were watered for the first 2–3 weeks of the growing season until they were well established. Thereafter, all mesocosms only received rainfall. The average annual air temperature was 14.0 °C and average precipitation was 83 mm, 98 mm, and 76 mm for each year, respectively. Weather data were obtained from Dulles International Airport, the weather station closest to the research compound.

2.2. Mesocosm hydrology and plant measurements

Water levels in all mesocosms were visually monitored at least biweekly during the three growing seasons to mimic the water regimes of created mitigation wetlands (i.e., moist soil up to 3 cm standing water) in the Virginia Piedmont (see Ahn and Dee, 2011). Water inputs in most mitigation wetlands in the region are due to precipitation; surface water perches due to water tables being close to the soil surface (Moser et al., 2007; Ahn and Dee, 2011; Dee and Ahn, 2012). All mesocosms were maintained under similar hydrologic conditions. During the first growing season, six mesocosms leaked and failed to consistently retain water and keep the soil moist, creating unexpected differences in hydrologic conditions amongst the mesocosms. We designated these leaky mesocosm as non-saturated or "dry" and saturated mesocosms as "wet". Natural wet meadows may have dry areas due to high microtopography (Moser et al., 2007) and plant communities in created mitigation sites may develop differently than planned based on unforeseen site extremes in hydrologic conditions (Whittecar and Daniels, 1999). Therefore, it was decided to retain these leaky mesocosms in the experiment and observe any effects of these hydrologic conditions on plant community development.

At the end of each growing season, all naturally-colonized vascular plants were identified to species level following Radford and Bell (1968) and Godfrey and Wooten (1979). Nomenclature was assigned according to Kartesz (2011). Taxon count of identified species was used to determine species richness for each mesocosm. Plant diversity was determined using the Shannon–Weiner diversity index (H') that takes into account both the number of species and their relative abundances (Hayek and Buzas, 2010; Jørgensen et al., 2005). For this study, diversity (H') was determined based on total plant cover, rather than by a count of individuals (Mitsch et al., 2005; *sensu* Moser et al., 2007). Percent cover for all species, collectively and individually for each mesocosm, was determined by placing wire mesh over a mesocosm and then counting the number of grids in which plants were present. Each grid in the wire mesh covered 50.58 cm^2 of the surface area of each mesocosm. Grid count was then converted to percent cover by multiply each count by a factor of 0.457. Total cover could exceed 100% due to overlap of plant leaves within a mesocosm.

All plants were assigned a regional (Region 1) wetland indicator status (Reed, 1988; Pepin, 2000). Wetland indicator status (WIS) values represent the probability that a species occurs in a wetland environment (Cronk and Fennessy, 2001). Assigned values are integers from 1 to 5; 1 = OBL (obligate, 99% probability of being found in wetlands), 2 = FACW (facultative wet, 66–99%), 3 = FAC (facultative, 33–66%), 4 = FACU (facultative upland, 1–33%), and 5 = UPL (upland, 1% probability of being found in wetlands). Notations of "+" and "−" indicate a slightly greater or lesser possibility of occurrence in a wetland, respectively. A prevalence index (PI) was determined for each species using weighted measurements (Wentworth et al., 1988; Dee and Ahn, 2012). Each mesocosm was assigned a PI value according to the weighted average of indicator ranks. The PI was calculated as $PI = \sum W_i A_i / \sum A_i$, where W_i is the wetland indicator category index value for species i, A_i is the percent cover directly determined for species i, and i is the individual species (Wentworth et al., 1988).

2.3. Data analysis

Data for all planted species and volunteers with 2% or more cover were included in our analyses. The independent variables were IPR and hydrology (wet vs. dry conditions). The dependent variables were total, planted, and volunteer cover percentages, AWD, S, H', and PI. All data were examined for normality. Repeated measures two-way ANOVA were carried out on all data and interactions using the General Linear Model (GLM), followed by a post-hoc test (Tukey's) for IPR and hydrologic condition. We also examined the effects of hydrologic condition on all vegetation attributes in the wet and dry mesocosms collectively to further investigate the impact of hydrologic conditions created in the early stage of the study. *T*-tests were performed on these data at a significance level of 0.05. All tests were carried out at significance levels of 0.05 and 0.01. All statistical analyses were carried out using IBM SPSS Statistics version 21.0 (SPSS, 2013).

3. Results and discussion

3.1. Species richness (S) and total percent coverage (TPC)

A total of 32 volunteer plant species were observed in the mesocosm wetlands (Table 1). Twenty-eight species are native to Virginia, while four (*Echinochloa crus-galli, Eleusine indica, Melilotus officinalis*, and *Trifolium pratense*) are introduced species. Sixteen species appeared during the first growing season. Seven new species were observed during the second season and nine additional new species during the third season. *Panicum virgatum* (switchgrass), a warm-season perennial grass designated as a facultative (FAC) was a volunteer and dominant species in every mesocosm by the end of the first growing season. Its TPC was highest in the two driest mesocosms. This species is known to grow on poor (i.e., nutritionally deficient and dry) soils and tolerates a wide range of pH and flooding (Barney et al., 2009). It has both upland and lowland ecotypes and has been planted in several created wetlands in Virginia (DeBerry and Perry, 2004; Ahn and Dee, 2011). TPC for this species was higher in leaking mesocosms (49%) than in non-leaking mesocosms (38%) during the first growing season. It was marginally present (TPC = 3%) in one of the leaking mesocosms in the second year and was absent thereafter, when the mesocosms supported higher levels of standing water. Five FAC+ or FACW+ sedge or rush species (*Carex vulpinoidea,*

Table 1
Plant species observed in mesocosms wetlands during three growing seasons.

Scientific name	Common name	WIS[a]	LS[b]	2010	2011	2012
Planted species						
Asclepias incarnata L.	Swamp milkweed	OBL	P	X	X	X
Carex vulpinoidea Michx.	Foxsedge	OBL	P	X	X	X
Juncus effusus L.	Soft rush	FACW+	P	X	X	X
Scirpus atrovirens Willd.	Bulrush	OBL	P	X	X	X
Scirpus cyperinus (L.) Kunth.	Woolgrass	FACW+	P	X	X	X
	Richness (S) of planted species[c]			5	5	5
Volunteer species						
Alisma subcordatum Raf.	Water plantain	OBL	P		X	X
Bidens aristosa (Michx.) Britton	Bearded beggar ticks	FACW−	A	X		X
Carex frankii Kunth	Frank's sedge	OBL	P		X	X
Carex lurida Wahl.	Shallow sedge	OBL	P		X	X
Chamaesyce maculata (L.) Small	Spotted sandmat	FACU−	A	X	X	X
Cyperus bipartitus Torr.	Flatsedge	FACW+	A	X		
Cyperus echinatus (L.) Alph. Wood	Flatsedge	FACU	P	X	X	X
Cyperus esculentus L.	Yellow nutsedge	FACW	P	X		
Cyperus odoratus L.	Fragrant flatsedge	FACW	A	X		
Cyperus polystachyos Rottb.	Many-spike flatsedge	FACW	A	X		
Cyperus strigosus L.	Straw-colored flatsedge	FACW	P	X	X	X
Dichanthelium clandestinum (L.) Gould	Deertongue grass	FAC+	P	X		
Digitaria sanguinalis (L.) Scop.	Hairy crabgrass	FACU−	A	X	X	X
Echinochloa crusgalli (L.) P. Beauv.	Barnyard grass	FACW−[d]	A		X	
Eleocharis obtusa (Willd.) Schult.	Blunt spikerush	OBL	A	X	X	X
Eleusine indica (L.) Gaertn.	Indian goosegrass	FACU−	A	X		X
Juncus acuminatus Michx.	Tapertip rush	OBL	P			X
Juncus tenuis Willd.	Poverty rush	FAC−	P		X	X
Leersia oryzoides (L.) Sw.	Rice cutgrass	OBL	P	X	X	X
Ludwigia alternifolia L.	Seedbox	FACW+	P			X
Ludwigia palustris (L.) Elliott	Marsh seedbox	OBL	P			X
Melilotus officinalis (L.) Lam.	Sweet clover	FACU−	B		X	
Mimulus alatus Aiton	Winged monkeyflower	OBL	P			X
Oxalis dillenii Jacq.	Slender yellow wood sorrel	UPL	P			X
Panicum virgatum L.	Switchgrass	FAC	P	X	X	
Paspalum laeve Michx.	Field paspalum	FAC+	P			X
Polygonum lapathifolium L.	Curlytop knotweed	FACW+	A	X		
Rotala ramosior (L.) Koehne	Common rotala	OBL	A	X	X	
Setaria parviflora (Poir.) Kerguélen	Marsh foxtail	FAC	P			X
Symphyotrichum dumosum (L.) G. Neesom	Rice button aster	FAC	P			X
Trifolium pratense L.	Red clover	FACU−	P			X
Typha latifolia L.	Broad-leaved cattail	OBL	P		X	X
	Richness (S) of volunteer species[c]			16	16	22

[a] Wetland indicator status for the Northeast Region (Region 1): OBL, obligate wetland species; FACW, facultative wetland species; FAC, facultative species; FACU, facultative upland species; UPL, obligate upland species; based on Reed (1988).

[b] LS, life strategy; where A, annual; B, biennial; P, perennial; based on Radford and Bell (1968).

[c] Richness values based on cover of 2% or greater in mesocosms during each growing season.

[d] Based on Pepin (2000).

Cyperus strigosus, Juncus effusus, Scirpus atrovirens, and *S. cyperinus*) were co-dominant with, or subdominant to, switchgrass during the first growing season.

Three FACU species (*Digitaria sanguinalis,Chamaesyce maculata*, and *Symphiotrichum ericoides*) were present in a least one mesocosm throughout all growing seasons. *Chamaesyce maculata* (spotted sandmat) was found only in dry, or non-saturated, mesocosms. All were present in the surrounding dry fields or unmowed portions of the mesocosm compound and produce many wind-dispersed seeds. The five experimental species were observed in their planted mesocosms throughout

Table 2
Vegetation attributes (mean ± SE) in mesocosms wetlands over three growing seasons.

Year	2010				2011				2012			
IPR	1	2	3	5	1	2	3	5	1	2	3	5
n	8	4	4	4	8	4	4	4	8	4	4	4
%Total cover	82 ± 9.1	81 ± 5.6	80 ± 13.2	86 ± 2.4	77 ± 6.8	65 ± 8.4	72 ± 11.4	78 ± 4.4	75 ± 5.9^{ab}	93 ± 6.6^{b}	63 ± 7.9^{a}	81 ± 6.8^{ab}
%Planted	30 ± 6.4	23 ± 2.7	27 ± 9.2	32 ± 7.7	77 ± 8.0	67 ± 7.0	71 ± 14.9	90 ± 2.4	60 ± 8.0	23 ± 8.5	55 ± 17.1	51 ± 13.9
%Volunteer	70 ± 6.4	77 ± 2.7	73 ± 9.1	68 ± 7.7	23 ± 8.0	33 ± 7.0	29 ± 14.9	10 ± 2.4	40 ± 8.0	77 ± 8.5	45 ± 17.1	49 ± 13.9
S	4.3 ± 0.4^{a}	5.0 ± 0.7^{a}	6.3 ± 0.3^{ab}	7.8 ± 0.8^{b}	3.4 ± 0.6^{a}	5.3 ± 0.6^{ab}	4.5 ± 0.9^{ab}	6.8 ± 0.5^{b}	4.9 ± 0.6	6.3 ± 0.9	5.3 ± 0.9	6.8 ± 1.0
H′	1.1 ± 0.1	1.2 ± 0.1	1.4 ± 0.1	1.5 ± 0.2	0.8 ± 0.2^{a}	1.4 ± 0.1^{ab}	1.2 ± 0.2^{ab}	1.5 ± 0.1^{b}	1.2 ± 0.2^{a}	1.5 ± 0.1^{ab}	1.5 ± 0.2^{ab}	1.7 ± 0.2^{b}
PI	2.4 ± 0.2	2.6 ± 0.1	2.3 ± 0.1	2.4 ± 0.1	1.7 ± 0.2	1.6 ± 0.4	1.6 ± 0.5	1.6 ± 0.0	1.5 ± 0.2	1.6 ± 0.6	1.3 ± 0.3	1.3 ± 0.2
WIS	FACW+	FACW−	FACW+	FACW+	OBL	OBL	OBL	OBL	OBL	OBL	OBL	OBL
AWD	3.2 ± 0.5	3.2 ± 0.8	3.2 ± 0.9	4.0 ± 0.0	8.4 ± 1.9	7.8 ± 2.6	6.7 ± 2.3	5.8 ± 2.4	5.7 ± 1.7	8.2 ± 2.8	7.2 ± 2.2	8.4 ± 2.3

Note: IPR, initial planting richness (S_{initial}); *n*, number of mesocosms planted; S, richness (at end of each growing season); *H′*, Shannon–Weiner diversity index; PI, prevalence index; WIS, wetland indicator status; AWD, average water depth (cm). Means with different letters within each year are significantly different ($p < 0.05$).

Table 3
Statistical results for each one of plant community characteristics as affected by initial planting richness and hydrology.

Source	Sum of squares	df	Mean square	*F*	Significance
Intercept	77.665	1	77.665	357.844	0.000
Hydro	0.304	1	0.304	1.401	0.026*
IPR	2.543	3	0.848	3.906	0.037*
Hydro x IPR	0.147	3	0.049	0.225	0.877
Error	2.604	12	0.217		

Variable		TPC (%)	Planted (%)	Volunteer (%)	S	*H′*	PI	AWD
IPR	F	0.82	2.09	2.09	7.95*	3.91*	1.60	0.48
Hydro	F	4.27*	3.00	3.00	3.06	1.40	17.30**	60.68**
Hydro x IPR	F	0.38	1.00	1.00	0.20	0.23	3.21	1.23

Note: TPC, total percent cover; S, species richness; *H′*, Shannon–Weiner diversity index; PI, prevalence index; AWD, average water depth in cm.

* $p < 0.05$.

** $p < 0.01$.

all growing seasons, although *Asclepias incarnata* contributed little to TPC.

Mean S was affected positively by IPR ($p = 0.003$), mostly due to differences between monotypic mesocosms (IPR = 1) and those with the greatest number of plantings (IPR = 5) (Tables 2 and 3). Richness values for our experimental mesocosm wetlands were greater ($p < 0.01$) for mesocosms with the highest IPR (IPR = 5) compared to mesocosms with monotypic plantings during the first two years (Table 2). However, the differences amongst IPR groups were not linear nor did they persist through the third growing season. Average *S* values decreased between the first and second growing seasons (*S* = 5.5 in 2010; *S* = 4.7 in 2011) and then appeared to stabilize in the third growing season (*S* = 5.6 in 2012). No interactions occurred between S, hydrologic conditions, and IPR (Table 3). Ahn and Dee (2011) noted a decrease in S between the second and third growing seasons in a created mitigation wetland in the Virginia Piedmont that our mesocosms were mimicking.

Total percent cover is the main plant community attribute used to identify wetlands and to evaluate the successful establishment of vegetation in wetland mitigation projects (USACE, 1987; Spieles, 2005). TPC varied over the course of this study (averages of 82%, 74%, and 77% over the three growing seasons, respectively) but failed to follow any pattern (Table 2). TPC of volunteer species for all mesocosms was high (72%) at the end of the first growing season due mainly to the presence of *Panicum virgatum* L. At the end of the second season, volunteers only contributed 22% and most of the TPC was contributed by the planted species. At the end of the experiment four volunteer OBL wetland species (*Eleocharis obtusa*, *Leersia oryzoides*, *Ludwigia palustris*, and *Typha latifolia)* formed 51% of TPC combined for all mesocosms.

Total plant cover and planted percent cover were higher (*t*-test, $p = 0.03$) in combined wet mesocosms than in combined dry mesocosms at the end of the second growing season with no difference in the first and the third year (Table 4).

A single stem of *Typha latifolia* (TPC < 1%) was noted in one “wet” mesocosm at the end of the first year, increasing its presence in five additional mesocosms over the next two years (5–32% second season, 7–48% third season). Five of the *Typha* mesocosms were “wet” (had standing water). This is consistent with Atkinson et al. (2010) findings in created depressional wetlands in southwestern Virginia. One “dry” mesocosm containing *Typha* decreased its TPC 50% between the second and third seasons. Although a native species, the cattail has the ability to increase its cover in natural wetlands (Shih and Finklestein, 2008). *Typha latifolia* might have the potential to become invasive within our experimental mesocosms. Therefore, a careful watch is needed for cattails as in any newly created wetlands to establish healthy vegetation communities.

Propagule dispersal can play an important role in the recruitment of volunteer species into developing wetland plant communities (Mitsch et al., 1998; Galatowitsch and van der Valk, 1996). With the exception of *Eleocharis obtusa*, the 21 volunteer species in the mesocosms (Table 1) were found growing in an adjacent stormwater wetland or damp fields draining into the research compound (unpublished data). Although the water volume of the pond increased after storm events, the pond did not flood into the mesocosm compound. Seeds of these volunteer species could have been dispersed into the mesocosms by wind or by animals noted in, or flying over, the research compound (Vivian-Smith and Stiles, 1994). Over a three year period following creation, 29 volunteer species were documented in wetlands created in the Virginia Piedmont (Ahn, 2010; Ahn and Dee, 2011). Therefore, fluctuations in volunteer S and TPC in the mesocosms can be regarded as part of normal community development rather than lack of sufficient propagule sources.

Table 4
Vegetation attributes in mesocosms wetlands (mean ± SE) as affected by two different hydrologic conditions (i.e., saturated/wet and not saturated/dry) over three growing seasons.

Year	2010		2011		2012	
Hydrologic condition	Wet	Dry	Wet	Dry	Wet	Dry
n	14	6	14	6	14	6
%Total cover	81 ± 5.8	84 ± 6.1	79 ± 3.7^a	61 ± 7.9^b	81 ± 4.7	69 ± 5.9
%Planted	29 ± 4.5	28 ± 4.8	81 ± 4.7^a	67 ± 10.5^b	56 ± 7.4	36 ± 9.2
%Volunteer	72 ± 4.5	72 ± 4.9	19 ± 4.7	34 ± 10.5	44 ± 7.4	65 ± 9.2
S	5.6 ± 0.5	5.3 ± 0.6	4.6 ± 0.5	4.7 ± 0.7	5.1 ± 0.5	6.8 ± 0.7
H′	1.3 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.2 ± 0.2	1.3 ± 0.1	1.7 ± 0.1
PI	2.3 ± 0.1	2.5 ± 0.1	1.4 ± 0.1^a	2.1 ± 0.3^b	1.2 ± 0.1^a	1.9 ± 0.3^b
WIS	FACW+	FACW	OBL	FACW+	OBL	OBL
AWD	4.0 ± 0.0^a	1.9 ± 0.8^b	9.7 ± 1.0^a	1.9 ± 0.7^b	9.5 ± 0.8^a	1.3 ± 0.4^b

Means with different letters within each year are significantly different (*t*-test, $p < 0.05$). S, richness (at end of each growing season); *H′*, Shannon–Wiener biodiversity index; PI, prevalence index; WIS, wetland indicator status; AWD, average water depth (cm).

By the end of the first growing season, 16 species were added to the original five species planted. Six and nine new species were added in the second and third growing seasons, respectively. These changes are typical of primary succession patterns in which open spaces offer habitable space to propagules of nearby species. Only two of these (*Oxalis dellenii* and *Trifolium pretense*) were UPL or FACU− species present in a 1–4 dry mesocosms, respectively. The remaining species were ≥FAC and were present in 1–3 wet mesocosms.

Species recruitment followed a successional pattern similar to that of a created planted riverine wetland in Ohio (Mitsch et al., 2005) and seeded created mitigation wetlands in the Virginia Piedmont (Ahn, 2010; Ahn and Dee, 2011). TPC was not affected by IPR, but was positively affected by hydrology ($p < 0.05$) (Tables 2 and 3) with higher coverage in a "wet" condition. However, there was no interaction between hydrology and IPR for TPC (Table 3).

Anderson (2007) suggested that the rate of S gain will decrease over time due to competition, and abiotic and dispersal limitations. Monitoring of the mesocosms for an additional two years will be carried out to determine if such a pattern, as well as changes in other vegetation characteristics, is observed in our experimental mesocosms throughout the five-year required monitoring period for created and restored wetlands.

3.2. Proportion of perennial species

In terrestrial systems such as Oklahoma tallgrass prairies, plant community development in the first year is typically dominated by annuals. Over time, perennial species join the community. The perennials gradually replace most of the annuals until the perennial species dominate the ecosystem (Collins and Adams, 1983). A similar pattern of succession occurs in freshwater wetlands (van der Valk, 1981). Using multiple vegetation indices, Matthews et al. (2009) evaluated the restoration progress of 29 wetlands in Illinois, including the proportion of perennial species. They noted an increase in the proportion of perennial species by the end of the third year. Therefore, we expected to see a large number of annuals growing in the first season in all of the mesocosms, both in terms of number of species and percent cover, followed by a gradual increase in the proportion of perennials.

Although we saw an increase in richness of perennial species over time there was a decrease in TPC of those perennials over the three growing seasons. No relationship, however, existed between perennial S or TPC and IPR. Our results are similar to those for a created wetland in southeastern Virginia (DeBerry and Perry, 2004). Conditions for the mesocosms and this created wetland are similar. Vegetation development at both sites was influenced by recruitment of propagules from an adjacent wetland, precipitation was the main form of water input, wetlands were shallowly inundated shortly after creation, and no nutrients were added to soils. The main difference between the two were that the created wetland was seeded with two grasses [*Panicum virgatum* (FAC) and *Lolium perenne* ssp. *multiflorum* (FACU)] for the purpose of stabilizing the soil whereas the mesocosm wetlands were planted with wetland species rhizomatous plugs. However, our mesocosm wetlands failed to follow the glacial marsh succession pattern described by van der Valk (1981). Several differences exist between our mesocosm ecosystems and van der Valk's wetlands. The greatest differences are creation scheme, the presence or absence of a soil seed bank, and drawdown conditions. Additionally, soil types and differences in soil nutrient concentrations may have played roles in developmental differences. van der Valk evaluated a naturally-occurring prairie glacial marsh in Eagle Lake, Iowa. The marsh contained seeds and fragments of potentially vegetative plant forms in its soil bank, whereas our soil source did not. Both sites experienced drawdowns. Annual wetland species became established during drawdowns in the glacial marsh whereas annual non-wetland species were recruited into those mesocosms that experienced prolonged or even permanent drawdowns (i.e., "dry" mesocosms) due to leaking. Post-drawdown flooding resulted in the germination of emergent species in the glacial marsh. Our mesocosms experienced two very different post-drawdown hydrologic conditions. Our "wet" mesocosms followed a similar pattern of vegetation development due to reflooding that followed the drawdowns. However, our "leaking" mesocosms experienced prolonged or even permanent drawdown or "dry conditions". This resulted in greater recruitment of annual and perennial non-wetland species. The prairie wetlands were also influenced by muskrat "eat out" of vegetation. Although we noted evidence of raccoon activity (i.e., footprints) in several mesocosms each year, no vegetation damage occurred. All of our planted species, except *Asclepias incarnata*, were perennials and likely skewed our initial results in favor of perennials.

3.3. Shannon–Weiner diversity index (H')

A variety of indices are used to describe "biodiversity" in biological systems or ecosystems. Measurements used to determine biodiversity include community organization, and genetic or species composition (Lyashevska and Farnsworth, 2012). For some studies that incorporate multiple species types, biodiversity continues to be limited to the measurement of species richness (*sensu* Kirkman et al., 2012; Paetzig et al., 2012). Gathering species richness data is frequently used in rapid assessments of biodiversity for large-scale conservation areas (Similä et al., 2006); however, use of only this metric may cause researchers to miss recognizing diversity in a variety of habitats (Lyashevska and Farnsworth, 2012). Additionally, studies may refer to "species composition" without defining this metric as frequency of individuals within a species or merely species richness. We used the Shannon–Weiner index (H') that incorporates both species richness (S) and species evenness (determined by abundance) in its definition of biodiversity.

The H' values for our experimental wetlands exceeded that for created seeded wetlands in the Virginia Piedmont (Ahn, 2010; Ahn and Dee, 2011). Over a three-year period, diversity in these created wetlands declined, whereas diversity in our experimental mesocosm wetlands increased. Species diversity was greatest in mesocosms with the highest number of species initially planted (IPR = 5) in each growing season (Table 2). Differences in mean H' values, as affected by IPR (Table 3), were significant in the second and the third year (Table 2). Although H' did not show a linear change over time, these results do show the lasting effect of IPR on plant community diversity (Table 3).

3.4. Prevalence index (PI)

Mean PI values decreased over time (Table 2) and were related to hydrology ($p < 0.01$). Prevalence indices for combined wet were significantly lower compared to combined dry mesocosms during the second and third growing seasons (Table 4). However, the AWD of the combined wet and combined dry mesocosms differed significantly for all three growing seasons (Table 4), showing clearly the accidental leakage of six mesocosms. However, PI was not affected by IPR nor was there any interaction between hydrology and IPR for PI (Table 3). The mean PI values (Table 2) for all four planting groups during the first year are comparable to those for created wetlands during their first growing season in various locations in the U.S. ($n = 4$, PI mean = 2.4, range = 1.8–3.1; Spieles, 2005). The PI values were also comparable to those for mitigation wetlands created in the Virginia Piedmont (PI mean = 2.8, range = 1.9–3.7 based on Ahn, 2010; Ahn and Dee, 2011).

A PI < 3.0 is required for wetland delineation (USACE, 1987). Spieles (2005) suggested that PI < 2.5 could be used to characterize successful vegetation development in created and restored wetlands. Applying this criterion, the changes in PI that we observed indicate that the mesocosm communities showed signs of successful development into wetlands both legally and ecologically (Table 2). While not affected by IPR, PI values continued to decrease over the three growing seasons. This indicates that each mesocosm was becoming more of a wetland, supporting facultative wet and obligate wet species over time as observed in many newly created wetlands (Ahn and Dee, 2011; Dee and Ahn, 2012). Our experimental mesocosms had a mean WIS status of FACW (Table 2); therefore, most of the total cover was derived from wetland plants. All of the mean PI values for the second and third years (average WIS = OBL) were lower than those for the first year. These PI values (range = 1.6–1.7) (Table 2) were lower than those noted by Spieles (2005) for created wetlands in their second year of growth ($n = 3$, PI mean = 2.54, range = 2.26–2.77), but comparable to those found by Ahn and Dee (2011) (PI mean = 1.5). Similar to natural or created large-scale wetlands, hydrology played a role in the establishment of the plant communities within our experimental wetlands. Hydrologic conditions (wet vs. dry) impacted TPC (Tables 2 and 4). Low AWD in mesocosms likely encouraged the recruitment of volunteer species in the first year. Expansion of TPC for the initially planted species and the recruitment of other wetland plants during the second and third growing seasons resulted from wetter conditions in those years. Decreases in PI resulted in assigning a wetter WIS status to the groups over time.

4. Conclusion

The study investigated the effects of IPR on several vegetation development indices that are commonly measured to track ecosystem development in created mitigation wetlands. The outcome showed the positive effect of IPR on S and H' in the early development of plant community. Current wetland mitigation practices do not mandate planting diversity, but planting richness can, and should be, considered in future planning and designing of wetland mitigation projects in an attempt to achieve diverse vegetation community establishment. The mesocosm wetlands were following a similar pattern found in vegetation community development trajectory of newly created mitigation wetlands in the Virginia Piedmont. Our findings also reinforce the importance of maintaining adequate hydrologic conditions for the early development of vegetation community in created mitigation wetlands. Drawdowns allow for the establishment of both wetland and non-wetland annual species. Follow-up flooding events can drown out upland species and allow emergent species to grow. Rhizomatous perennials can emerge annually post flooding to outcompete non-wetland annuals when hydrologic conditions are adequate. Additional study of biogeochemical properties (e.g., biomass production, biomass decomposition, and soil organic matter accumulation) is needed to determine what control these may exert over the developing plant community structure.

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