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CASE-BASED ARTICLE

Macroinvertebrate community convergence between natural, rehabilitated, and created wetlands

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Wetland restoration practices can include rehabilitating degraded wetlands or creating new wetlands. Empirical evidence is needed to determine if both rehabilitated and created wetlands can support the same macroinvertebrate communities as their natural counterparts. We measured long-term macroinvertebrate community change in seasonal wetlands known as Delmarva Bays in Maryland, U.S.A. We compared a rehabilitated, a created, and a natural Delmarva Bay. We hypothesized that the created and rehabilitated wetlands would develop different macroinvertebrate communities. We also hypothesized that the community composition of the rehabilitated wetland would become more similar to that of the natural wetland than to that of the created wetland over 9 years encompassed by this study. We monitored the macroinvertebrates, including both predators and primary consumers, and environmental conditions in the three wetlands from March to August in 2005, 2006, 2007, and 2012. Cluster analysis indicated that from 2005 to 2007, the macroinvertebrate community of the rehabilitated wetland and the created wetland were more similar to each other than to the natural wetland. In 2012, the rehabilitated wetland was more similar to the natural wetland than to the created wetland. This similarity was driven principally by changes in the composition of primary consumer taxa. Our results suggest that rehabilitated Delmarva Bays are more likely to support a natural macroinvertebrate community than are created wetlands. Restoration practices that rehabilitate existing wetlands may be preferred over practices that create new wetlands when restoration project goals include developing natural macroinvertebrate communities in a short period of time.

Key words: Delmarva Bays, Maryland, primary consumers, restoration practices

Implications for Practice

- Wetland rehabilitation is more likely than wetland creation to restore a macroinvertebrate community that approximates that of a natural wetland. Therefore, wetland rehabilitation is typically a more effective strategy than wetland creation for protecting and promoting ecosystem services linked to the presence of wetland macroinvertebrates.
- The results of wetland rehabilitation are evident in changes in the composition of primary consumers. Specifically, the transition from a community dominated by larvae of non-biting midges to one dominated by freshwater isopods suggests that a macroinvertebrate community comparable to natural forested depressional wetland was established in the rehabilitated site in a relatively short time-period.

Introduction

Wetlands provide valuable ecosystem services such as flood regulation and nutrient retention/cycling, which are supported by a diverse community of wetland species (Hansson et al. 2005). Anthropogenic development threatens the services provided by wetlands and the ability of wetlands to maintain natural communities (Ghermandi et al. 2008). Thus, management of wetland ecosystems in human-dominated landscapes is necessary to protect wetland species and the ecosystem services they provide.

Wetland management approaches vary from protection and preservation to rehabilitation of existing wetlands or construction of new wetland habitat (Grenfell et al. 2007). These approaches have different results because they can yield different physical and biological conditions (Whigham 1999). This study focuses on the recovery of the macroinvertebrate community in response to wetland rehabilitation and creation, both of which we broadly refer to as restoration. Here, we refer to

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wetland rehabilitation as any process that reinstates specific soil, vegetation, and hydrology characteristics in existing but degraded wetland habitat. Wetland creation introduces these characteristics where a wetland does not currently exist.

Delmarva Bays are non-tidal depressional wetlands located on the peninsula of Delaware, Maryland, and Virginia, U.S.A. They typically dry during summer (Pickens & Jagoe 1996), which creates hydrologic conditions that support a suite of rare plant and animal species unique to this specific type of wetland environment (McAvoy & Bowman 2002). Macroinvertebrates occupy all trophic levels (Culler et al. 2014), and fish are typically absent, as these are seasonal wetlands. Agricultural activity on the Delmarva Peninsula has destroyed or degraded approximately 70% of Delmarva Bay habitat (Fenstermacher et al. 2014), prompting wetland restoration to mitigate habitat loss. Restoration of Delmarva Bays has included both wetland creation and rehabilitation through measures such as plugging drainage ditches surrounding agricultural fields, girdling encroaching trees, and restoring natural hydrological fluxes from groundwater.

As part of a larger restoration effort at the Jackson Lane Preserve in Maryland, we compared the long-term aquatic macroinvertebrate community change of a created wetland and a rehabilitated Delmarva Bay to a natural Delmarva Bay (Fig. 1). Hereafter, we refer to all the locations sampled as wetlands. The goal of our research was to determine if macroinvertebrate communities would respond differently to rehabilitation versus creation approaches. In addition, we wanted to determine if the rehabilitation of an existing wetland would result in a community more representative of a natural wetland than would occur through wetland creation. We hypothesized that the macroinvertebrate community developed during the 9-year period after restoration would differ between rehabilitated and created wetlands. We also hypothesized that, after 9 years, the macroinvertebrate community of the rehabilitated wetland would more closely mimic that of the natural wetland than that of the created wetland.

Methods

Site Description

The Jackson Lane Preserve is a 107 ha wetland complex in the Choptank River watershed in Caroline County, Maryland (39°03′11.9″N, 75°44′50.2″W). In the 1970s, several Delmarva Bays were drained for use as cropland and cattle pasture. In 2003, The Nature Conservancy, in partnership with U.S. Fish & Wildlife Service, Maryland Department of the Environment, and the Natural Resource Conservation Service, restored the site.

Restoration included two components. The first involved rehabilitating a degraded Delmarva Bay, formerly used as a cattle pasture (Fig. 2). This pond was ditched and partially drained in the 1970s, which reduced its overall size, altered its hydrology, and facilitated encroachment by surrounding trees. Rehabilitation included plugging drainage ditches and girdling or removing encroaching trees and vegetation. Size

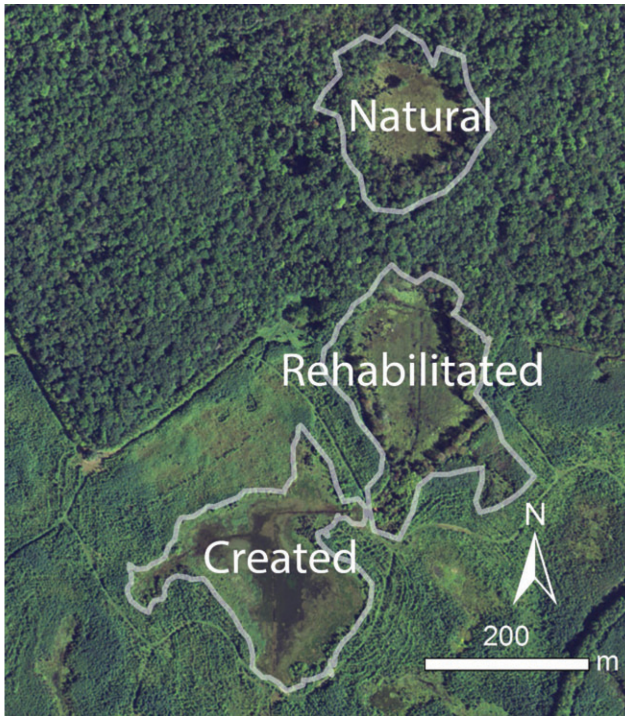

Figure 1. An aerial photograph of wetlands from the Jackson Lane Preserve sampled for this study.

of this wetland after rehabilitation was 3.3 ha. The dominant species at this wetland before rehabilitation included *Carex striata* (Walter's sedge), *Bidens frondosa* (Devil's beggartick), *Chasmanthium laxum* (Slender woodoats), and *Rubus hispidus* (Bristly dewberry). These species were replaced by *Ludwigia sphaerocarpa* (Globe-fruited false-loosestrife), *Proserpinaca pectinata* (Mermaid weed), and *Polygonum hydropiperoides* (Swamp smartweed) after rehabilitation (Samson et al. 2011). *Sphagnum cuspidatum* (Toothed sphagnum) is commonly associated with Delmarva Bays and was first recorded in 2009 (6 years after the project began).

The second component of the Jackson Lane restoration project involved creating 30 new wetlands. Locations for created wetlands were selected by using topographic maps to identify natural depressions. The single created wetland included in our study (Fig. 3) was constructed using an earthen berm to block the drainage ditch adjacent to the wetland. Microtopography was created within the wetland using a backhoe. Seedling trees were planted along edge habitat and straw was added to prevent cattail (*Typha* sp.) colonization. Coarse woody debris was added to increase habitat heterogeneity. The total size of this wetland after restoration was 3.7 ha. Vegetation transects indicate that wetland plants did become established. Dominant plant species included *Scirpus cyperinus* (Kunth woolgrass), *Ludwigia palustris* (Marsh seedbox), *Eleocharis obtusa* (Blunt spikerush), and *Lemna minor* (Common duckweed; Samson et al. 2011).

We also sampled an existing natural wetland in the Jackson Lane Preserve (Fig. 4). Its vegetation, soil, and hydrology were characteristic of a Delmarva Bay prior to the project, and

Figure 2. Pictures of the rehabilitated wetland from May 2003 (left) to June 2012 (right).

Figure 3. Pictures of the created wetland from August 2003 (left) to 2012 (right).

Figure 4. Pictures of the natural wetland from June 2003 (left) to August 2012 (right).

aerial photography indicated that it was not altered by human activity. The soil, classified as Corsica mucky loam (fine-loamy, mixed, active, mesic Typic Umbraquults), is saturated most of the year, but drying often occurs in summer with refilling in autumn. The size of this wetland is 1.3 ha. The dominant plant species at this wetland between 2005 and 2012 were *C. striata*, *Cephalanthus occidentalis* (Common buttonbush), *Acer rubrum* (Red maple), *Triadenum virginicum* (Virginia marsh St. Johnswort), and *Liquidambar styraciflua* (Sweetgum; Samson et al. 2011). The bryophyte *S. cuspidatum* was present at the natural wetland throughout the study.

Sampling

Following restoration, we took monthly samples at the natural, rehabilitated, and created wetlands from March through August, as long as they retained water, during 2005, 2006, 2007, and 2012 (Fig. 1). In total, we collected 22 samples at the created wetland, 20 samples at the restored wetland, and 18 samples at the natural wetland. A full record of all dates sampled can be found in the online material (Table S1, Supporting Information). We designed this research as a case study, similar to a before-after control-impacted (BACI) experiment, focused on examining temporal changes in these three wetlands. However, the characteristics of the natural wetland are consistent with those of a Delmarva Bay, including water chemistry (Pickens & Jagoe 1996) and macroinvertebrate community composition (Batzer et al. 2005). Within this context, the changes that took place at both the rehabilitated and created wetlands are likely to be informative beyond this study system.

Our sampling procedures follow the protocol described by Culler et al. (2014). Summarized briefly, we measured pH and conductivity with a YSI 63 Model Probe (YSI Inc., Yellow Springs, OH, U.S.A.) and analyzed water samples for total nitrogen (TN), total phosphorus (TP), and chloride (Cl). TN and TP were measured as the total amounts of either nitrogen or phosphorus present in the sample on a mass basis, including inorganic forms as well as in dissolved and particulate matter. Concurrently, we sampled macroinvertebrates by conducting 20 sweeps at each wetland with a 500 μm D-net with a cross-sectional area of 622 cm^2. One sweep constituted disturbing a 1-meter long section of sediment and vegetation and passing the net through the water to capture macroinvertebrates. Samples were washed to remove debris and then preserved in 80% ethyl alcohol. Macroinvertebrates were removed from subsamples until we reached ≥200 individuals (King & Richardson 2002). We identified macroinvertebrates to the lowest practical taxonomic level (typically genus).

Data Analysis

Values for pH, conductivity, Cl, TN, and TP were averaged over each year to compare changes within and among wetlands among years. We also used the function *prcomp* (R Core Team 2014) to perform a principal components analysis (PCA) on centered and standardized monthly water chemistry samples to evaluate how pH, conductivity, Cl, TN, and TP contributed to differences between wetlands.

All analyses of macroinvertebrate community composition were performed on data summed across monthly samples for each year for each wetland. We calculated relative abundances for each taxon and used these abundances to compare the five most abundant taxa for each year from the natural wetland to their abundances in the rehabilitated and created wetlands. We also calculated Shannon diversity, taxa richness, primary consumer relative abundance, and predator relative abundance (Merritt & Cummins 1996).

We used the *hclust* function from the stats package in R (R Core Team 2014) to perform hierarchical cluster analysis, which grouped yearly samples based on Bray–Curtis dissimilarities to assess changes in the macroinvertebrate communities through time. Samples were designed to be representative of each wetland, and we had a systematic sampling design. Thus, groups were formed using the unweighted pair group method with arithmetic mean (Legendre & Legendre 2012).

Similarity percentage was calculated between the main groups identified by cluster analysis using the *simper* function from the vegan package in R (Oksanen et al. 2015), which provides the average contribution of each individual taxon to Bray–Curtis dissimilarities between assigned groups (Clarke 1993). Based on the cluster analysis, we calculated similarity percentage based on the groups identified by the first split in the dendrogram (Fig. 6).

Results

Water Chemistry

In general, conductivity, pH, Cl, TN, and TP were lowest in the natural wetland, highest in the created wetland, and intermediate in the rehabilitated wetland (Table 1). Seasonal variation appeared consistent within each wetland across years. The PCA biplot has two axes that account for 87% of the variance between samples (PC1 = 65%, PC2 = 22%, Fig. 5). All water chemistry measures are negatively correlated with PC1, whereas pH, conductivity, and Cl are negatively correlated with PC2, and TN and TP are positively correlated with PC2.

Macroinvertebrate Community

A total of 13,801 individuals, representing 12 macroinvertebrate orders and 30 insect families were processed during the study (see the supporting information for a full record, Table S1). Shannon diversity was lowest at the natural wetland in each year, highest at the rehabilitated wetland in 2005 and 2006, and highest at the created wetland in 2007 and 2012 (Table 2). The lowest proportion of predators (4%) was observed at the natural wetland in 2012, whereas the highest proportion (46%) was observed at both the natural and rehabilitated wetland in 2007 (Table 2).

Caecidotea (freshwater isopod) was the most abundant taxon at the natural wetland in all years and was absent from the rehabilitated and created wetlands until 2012. In 2012, *Caecidotea* represented 75% of the community of the natural wetland, 59% of the rehabilitated wetland, and 9% of the created wetland

Table 1. Yearly means and standard deviations of water chemistry characteristics for the three wetlands.

	Year	*Conductivity (μS/cm)*	*pH*	*Chloride (ppm)*	*Total Nitrogen (ppm)*	*Total Phosphorus (ppm)*
Natural	2005	40.2 ± 6.9	4.6 ± 0.2	1.6 ± 0.8	1.9 ± 0.5	0.07 ± 0.05
	2006	36.2 ± 8.5	4.6 ± 0.1	1.6 ± 1.1	1.8 ± 0.3	0.06 ± 0.02
	2007	27.6 ± 16.5	4.9 ± 0.1	2.7 ± 1.7	1.3 ± 0.7	0.06 ± 0.06
	2012	24.4 ± 2.0	4.8 ± 0.0	1.8 ± 0.3	2.6 ± 2.3	0.15 ± 0.21
Rehabilitated	2005	37.1 ± 10.4	5.4 ± 0.3	2.3 ± 1.5	2.1 ± 0.8	0.07 ± 0.04
	2006	52.8 ± 11.2	5.5 ± 0.1	4.3 ± 2.3	2.5 ± 0.5	0.10 ± 0.03
	2007	28.8 ± 3.6	5.2 ± 0.3	1.7 ± 1.1	4.4 ± 6.4	0.24 ± 0.42
	2012	25.0 ± 4.6	5.1 ± 0.1	2.0 ± 0.9	2.4 ± 1.8	0.07 ± 0.08
Created	2005	65.5 ± 11.4	7.0 ± 0.3	3.1 ± 1.8	2.1 ± 0.7	0.12 ± 0.06
	2006	80.6 ± 23.0	7.1 ± 0.2	5.6 ± 2.9	2.6 ± 0.8	0.17 ± 0.06
	2007	68.9 ± 46.5	6.9 ± 0.2	6.9 ± 7.5	9.3 ± 11.3	0.70 ± 0.84
	2012	60.7 ± 37.1	6.8 ± 0.2	5.6 ± 6.0	4.0 ± 3.3	0.26 ± 0.25

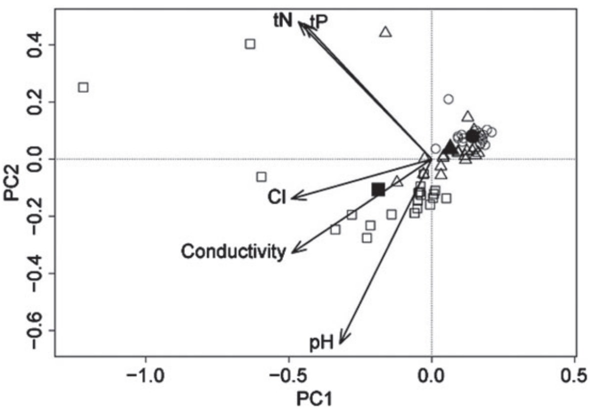

Figure 5. Principle components analysis showing water chemistry data from created, rehabilitated, and natural wetlands. Triangles represent the rehabilitated wetland, squares represent the created wetland, and circles represent the natural wetland. Open shapes represent individual monthly samples, and solid shapes represent the centroid for the monthly samples for each wetland.

(Table 3). In 2005, the five most abundant taxa at the natural wetland comprised 94% of that community. These same five taxa represented 32 and 40% of the communities of the rehabilitated wetland and created wetland, respectively. In 2012, the five most abundant taxa at the natural wetland comprised 96% of that community. These taxa represented 77% of the rehabilitated wetland community, but only 42% of the created wetland community (Table 3).

Cluster analysis separated the yearly community samples into two main groups (Fig. 6). One group included all years of the natural wetland as well as 2012 data from the rehabilitated wetland. The other group included all years from the created wetland as well as 2005–2007 from the rehabilitated wetland. *Caecidotea* contributed 37% to the Bray–Curtis dissimilarities between the two main groups. The next most important taxa were Chironomini (9%), Tanytarsini (6%), Orthocladiinae (5%), and Tanypodinae (5%). All other taxa contributed less than 5% to the taxonomic differences among sites.

Discussion

We found that (1) the macroinvertebrate communities differed between the rehabilitated and created wetlands and (2) the 2012 community of the rehabilitated wetland was more similar to the natural than created wetland community. This result suggests that different restoration processes produce different abiotic

Table 2. Diversity metrics for each wetland based on the sum of each taxon across monthly samples for each year. Relative abundance for predators and primary consumers are included.

	Year	*Diversity*	*Taxa Richness*	*Predator (%)*	*Primary Consumer (%)*
Natural	2005	1.42	27	17	83
	2006	1.68	36	25	75
	2007	1.50	19	46	54
	2012	1.00	20	4	96
Rehabilitated	2005	2.66	40	38	62
	2006	2.22	35	39	61
	2007	1.63	29	46	54
	2012	1.67	31	21	79
Created	2005	2.48	40	23	77
	2006	1.89	33	22	78
	2007	1.96	28	39	61
	2012	1.79	25	36	64

Table 3. The five taxa with the highest relative abundance from the natural wetland compared to their relative abundances for the rehabilitated and created wetlands. Abundances are presented as percentages.

	Order: Taxon	*Natural*	*Rehabilitated*	*Created*
2005	Isopoda: *Caecidote*a	59	0	0
	Diptera: Chironomini	16	18	27
	Diptera: *Bezzia*	10	8	8
	Diptera: Sciaridae	6	1	0
	Diptera: Tanypodinae	3	5	5
	Other	6	68	60
2006	Isopoda: *Caecidotea*	58	0	0
	Diptera: *Bezzia*	11	10	4
	Diptera: Tanypodinae	9	14	10
	Diptera: Orthocladiinae	6	37	5
	Diptera: Chironomini	4	8	3
	Other	12	31	77
2007	Isopoda: *Caecidotea*	44	0	0
	Diptera: *Bezzia*	35	29	5
	Diptera: Tanypodinae	7	7	29
	Diptera: Chironomini	3	47	28
	Amphipoda: *Gammarus*	3	0	0
	Other	8	16	38
2012	Isopoda: *Caecidotea*	75	59	9
	Gastropoda: Ancylidae	12	11	0
	Diptera: Chironomini	5	3	32
	Amphipoda: *Gammarus*	4	0	0
	Odonata: Coenagrionidae	2	4	1
	Other	4	23	58

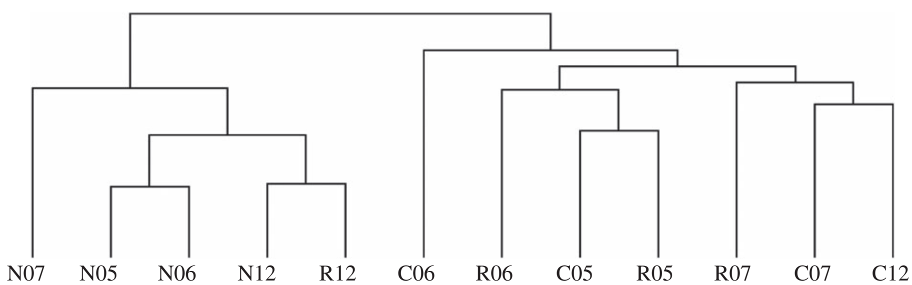

Figure 6. A dendrogram displaying the results of cluster analysis performed on Bray–Curtis dissimilarities calculated between macroinvertebrate community samples summed for each wetland for each year. Branches are designated N (natural), R (rehabilitated), or C (created) and labeled with the year (2005, 2006, 2007, or 2012).

habitat conditions (Steven & Lowrance 2011) and rehabilitated wetlands likely support macroinvertebrate communities more typical of natural than created wetlands within a short-time period similar to the 9 years of this study (Whigham 1999).

Water chemistry varied seasonally at all three wetlands. Water chemistry characteristics of the rehabilitated wetland appear to be more similar to those of the natural wetland than to the created wetland. Both the natural and rehabilitated wetlands had the high acidity characteristic of Delmarva Bays (Pickens & Jagoe 1996), which is attributed to surficial groundwater and accumulated vegetative material (Newman & Schalles 1990). This may indicate that the habitat characteristics of the rehabilitated wetland were more similar to those of the natural wetland. However, the water chemistry conditions of the three wetlands were unlikely to prevent colonization or establishment of most wetland macroinvertebrates (Gorham & Vodopich 1992). Thus, we believe that differences in water chemistry among wetlands likely did not control composition of macroinvertebrate communities once established.

The macroinvertebrate community of the rehabilitated wetland was more similar to that of the created than the natural wetland from 2005 to 2007, but was more similar to that of the natural than created wetland in 2012. This change in community similarity was attributed primarily to a change in primary consumer taxa in the rehabilitated wetland between 2007 and 2012. In 2012, the rehabilitated wetland shifted from numerical dominance by chironomids to *Caecidotea*, an organism that may be an indicator of restoration success. The ecology of *Caecidotea* is not well understood, though they are typically abundant in southern forested depressional wetlands such as Delmarva Bays (Batzer et al. 2005). We have observed them clustered on wetland grasses and believe that they were likely feeding on periphyton, which suggests they are primary consumers (E. Spadafora 2012, University of Maryland).

We found other community differences among the three wetlands, most notably that diversity was consistently lowest at the natural wetland. Although low diversity at the natural site may seem counterintuitive, it is not unexpected given that the natural wetland is acidic and oligotrophic. Although the created wetland consistently had the most diverse community, we do not consider this to be an indication of restoration success for our system as community composition differed substantially from the natural wetland. However, this result suggests that wetland creation may still result in a macroinvertebrate community that supports certain ecosystem services. Thus, the decision to utilize rehabilitation or creation approaches should consider the need for restored sites to match the conditions of the types of wetland being restored. In our case, replicating the conditions of natural Delmarva Bays was essential given their unique nature and widespread impacts from land development in the region.

At all wetlands, taxa richness and percent predators versus primary consumers varied considerably year-to-year. These differences could be explained by wetland vegetation composition (De Szalay & Resh 2000), hydrology (Dietz-Brantley et al. 2002), and disturbance (Tangen et al. 2003). For example, a drought in 2007 caused several nearby wetlands to dry earlier in the year (Culler et al. 2014). Continued monitoring of abiotic and biotic changes in rehabilitated and created wetlands is needed to determine how these factors influence macroinvertebrate diversity and succession as they relate to natural, unimpacted wetlands.

Our study was designed to focus on the long-term monthly and yearly changes that occurred in restored wetlands. This approach resulted in temporal but not spatial replication of wetland restoration types. Thus, the inferences we make about different restoration approaches are limited. However, our overall conclusions about the effectiveness of rehabilitation versus creation are based on a change in community composition (i.e. the dominance of isopods) that was clearly documented and represented a long-term stable condition in the natural wetland. Although our study represented a substantial sampling effort, the conditions in the study wetlands will continue to change. The conditions in the created wetland may approach what is found in the natural and rehabilitated wetlands if given sufficient time to develop. Thus, the advantages of rehabilitation over creation may only apply to projects that seek to improve macroinvertebrate communities over short periods of time (i.e. about 9 years).

Our results suggest that rehabilitated wetlands are more likely to recover macroinvertebrate communities of their natural counterparts than are created wetlands, though recovery may not be apparent within the first two to four years after restoration measures are taken. As the composition of macroinvertebrate communities are linked to ecosystems services the wetland will provide, wetland rehabilitation should be prioritized over wetland creation, and both should be coupled with long-term monitoring programs to assess success.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. A record of all macroinvertebrates processed as a part of our study between 2005 and 2012 from the Jackson Lane Wetland Preserve, in Caroline County, Maryland, U.S.A.

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