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Agricultural wetland restorations on the USA Atlantic Coastal Plain achieve diverse native wetland plant communities but differ from natural wetlands

Metthea Yepsen [a,*], Andrew H. Baldwin [a], Dennis F. Whigham [b], Eliza McFarland [b], Marina LaForgia [b], Megan Lang [c]

[a] University of Maryland, Department of Environmental Science and Technology, 1423 Animal Science Building, College Park, MD 20740, United States
[b] Smithsonian Environmental Research Center, 647 Contees Wharf Road, Edgewater, MD 21037, United States
[c] USDA Forest Service, Northern Research Station, 10300 Baltimore Avenue, Building 007, Room 104 BARC-West, Beltsville, MD 20705, United States

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ABSTRACT

Wetland restoration is globally important for offsetting effects of wetland loss and degradation but is not consistently successful. Vegetation studies provide insight into the effectiveness of restoring wetland ecosystem functions. We compared plant community composition in 47 non-tidal wetlands under different management (natural, restored, and former wetlands that had been converted to cropland) in the Atlantic Coastal Plain of the USA. As expected, drained cropland sites were dominated by conventional upland row crops, had low species richness and evenness, and were highly disturbed. Plant communities in restored sites were more like natural sites based on the percentage of species that were native and hydrophytic, plant community evenness, and floristic quality. However, natural sites were forested, while restored and drained cropland sites were primarily herbaceous. Restored sites continued to be impacted by anthropogenic disturbance compared to natural sites. Our findings demonstrate that restored wetlands in agricultural settings can develop diverse native wetland plant communities within a decade but they remain very different from natural wetlands, raising questions about restoration goals, ecosystem service tradeoffs, and our ability to restore wetlands to ecological conditions found in reference sites.

1. Introduction

The wetlands of the world provide more ecosystem services per area than any other habitat type (Costanza et al., 1997; Dodds et al., 2008). They store and clean water, sequester carbon, provide habitat for diverse and often rare plants and animals, and are popular recreation spots (Dodds et al., 2008; Hefting et al., 2013; Hubbard and Linder 1986; Millennium Ecosystem Assessment 2005; Ullah and Faulkner 2005). The loss of ecosystem services when wetlands are degraded or converted to other land use types is well documented, as are global rates of wetland loss that range from 30 to 90% by region (Dahl et al., 1990, 2011; Junk et al., 2012; Zedler and Kercher, 2005).

In order to slow and reverse the rate of wetland loss and benefit from the services they provide, the United States of America (USA) and many other nations have implemented programs to protect and restore wetlands. The USA Department of Agriculture (USDA), for example, provides financial and technical assistance to landowners to help protect, restore, and enhance wetlands, primarily through two voluntary initiatives: the Wetland Reserve Program (WRP) and the Conservation Reserve Program (CRP)–Wetland Initiative. Stated objectives of WRP and CRP-Wetlands Initiative include protecting wetlands; providing habitat for migratory birds and other wetland-dependent fauna and flora; protecting and improving water quality by trapping sediment and removing nutrients; attenuating floodwater; recharging ground water; protecting and improving aesthetics of open spaces; and contributing to education and scientific knowledge. According to the technical guidelines for wetland restoration under these programs, ecosystem services are provided by returning the "soil, hydrology, vegetation and habitat conditions of the wetland that previously existed on the site to the extent

* Corresponding author. Present address: The Nature Conservancy, 2350 Route 47, Delmont, NJ 08314, United States. Tel.: +1 610 401 6166.
E-mail address: Metthea.m.yepsen@gmail.com (M. Yepsen).

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practicable". These conditions may be determined by historic documentation or through the use of a reference site (USDA NRCS Manual Title 440 Wetland Reserve Program, 2010; USDA NRCS Practice Standard Code 657, 2010).

Conceptually, restoration is the process of returning an ecosystem to a pre-anthropogenic-disturbance state. In practice, specific features or services are targeted for restoration rather than attempting a complete ecosystem restoration. Wetland restoration is a complicated process, in part, because wetlands are regionally distinct and the actions required to restore them to the functional equivalency of natural wetlands have been shown to be difficult to prescribe broadly (Zedler and Callaway, 1999). In many cases, restoration efforts have failed to return the biological and biochemical features to levels found in natural wetlands even after many decades (Benayas et al., 2009; Moreno-Mateos et al., 2012). Restored wetlands also tend to differ physically from their original condition. In the USA, for example, most non-tidal wetland restorations have resulted in the formation of ponds with a fringe of emergent marsh, regardless of what type of wetland they were historically. As a result, few restored wetlands match reference conditions (Cole and Shafer 2002; De Steven et al., 2010; Kentula et al., 1992).

In a typical year, all of the approximately $500 million WRP budget and more than 11% of the $1.8 billion CRP budget are spent on wetland restorations (American Planning Association, 2010; personal communication, Alexander Barbarika, Farm Service Agency). The return on these investments can be difficult to determine due to the complexity and cost of measuring ecosystem functions. The USDA's Natural Resources Conservation Service (NRCS) has implemented a national project to assess the effectiveness of conservation practices and programs through the Conservation Effects Assessment Project (CEAP). It is under CEAP that the research in this paper was conducted.

Due to the difficulty and expense of measuring multiple ecosystem functions as metrics of restoration success, rapid field assessment methods have been developed to facilitate quantification of biological indicators of ecosystem integrity (Fennessy et al., 1998, 2004; Lopez and Fennessy, 2002). Karr and Dudley (1981) defined ecosystem integrity as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of natural habitats of the region". Rapid field assessments are used to describe overall ecosystem condition, suggest probable causes of poor conditions, identify human activities that contribute to degradation, monitor wetland restoration trajectories, and set and assess measurable goals (Cronk and Fennessy, 2001; Galatowitsch et al., 1999).

Plants are one of the easiest and most frequently used indicators for assessing the progress of a wetland restoration (Mitsch and Wilson, 1996). They are adapted to natural variations in conditions and can reflect current as well as historic conditions (Bedford 1999; Cronk and Fennessy, 2001; Wilcox et al., 2002). Plant communities also respond to human disturbance in predictable ways. For example, the proportion of weedy species tends to increase with human disturbance and, given extreme disturbance, plants tend to decrease in size of individuals, cover, and lifespan (Karr, 1993). Advantages of using plants as biological indicators include: they are present in most wetland ecosystems; they are relatively easy to identify; sampling methods are well established; and their relative immobility creates a direct link between onsite environmental conditions and plant community characteristics (Cronk and Fennessy, 2001). Because of these traits, plant communities provide a good way to compare wetland conditions under different types of management.

We compared plant communities in two hydrogeomorphic wetland classes (depression and flat wetlands; Brinson, 1993; Brooks et al., 2011) under different management practices on the Atlantic Coastal Plain of the USA. Our goals were to (1) compare plant communities in restored wetlands and natural wetlands as well as in drained croplands that were previously wetlands, and (2) determine the degree to which each of the habitat types were impacted by human disturbance. Specifically, we used plant species composition and indices of diversity, floristic quality, and anthropogenic disturbance to compare management practices. We expected to find differences in plant communities between the habitat types due to their land use history and because the group of restored sites that were chosen were only 3–11 years in age. Even though the restored sites were relatively young, we sought to test the hypothesis that restored ecosystems are on a trajectory to having high ecosystem integrity, based upon the presence of seedlings and saplings of species found in natural sites.

2. Methods

2.1. Study sites

Forty-seven sites were selected for comparison in the USA Atlantic Coastal Plain regions of Delaware, Maryland, Virginia, and North Carolina (Fig. 1). The sites consisted of 14 "natural" wetlands, 16 "drained cropland" sites, and 17 "restored" wetland sites. Natural and drained cropland sites were identified using aerial photography and digital elevation models. They were selected to serve as references and controls for restored sites by minimizing natural differences (i.e., geomorphology, soil, and geographic proximity) and maximizing land use history differences. Natural sites were relatively undisturbed shallow wetlands characterized as either depressions or flats as described by Brinson's hydrogeomorphic classes (1993). They ranged in size from approximately 0.04 to 4.01 ha (mean = 1.58, SD = 1.6; estimates calculated via remote mapping of 7 out of 14 natural sites; calculations were difficult due to canopy cover and in some cases flat terrain). Depressions and flats are seasonally flooded and only occasionally connected to other wetlands via surface water. The drained croplands were once natural depression or flat wetlands, but had been drained hundreds of years prior to restoration for agricultural use. The restored wetlands were drained croplands that had been restored to depression wetlands. They ranged in age from 3 to 11 years since restoration and in size from 0.12 to 1.13 ha (mean = 0.53, SD = 0.38). As part of the restoration process, hydrology was restored either by plugging ditches or by excavating and compacting cropland to create shallow perched water table depressions often with water retention berms. Hummocks or islands were installed in the depressions of most restored sites in order to create within-wetland microtopographic diversity. Some of the restored sites had been planted with trees and most were planted with upland grasses on berms and in buffer areas.

2.2. Plant community survey

Plant community surveys were conducted once in each of the 47 sites from late June through September 2011 at the peak of the growing season to minimize differences due to time of year. The areas sampled in natural and restored wetlands were within the wetland boundary as roughly delineated by the plant community shift from wetland to upland plants. Ponded areas (i.e., standing water) without vegetation were not sampled. Drained cropland sites were sampled within approximately 25 m of the center of the wettest drained area. Given adequate area, three 10 m × 10 m quadrats (adapted from Peet et al., 1998) were randomly selected per plant community at each site. Plant communities within each wetland were visually