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Restoration of denitrification in agricultural wetlands

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ABSTRACT

Wetland restoration of abandoned farmland may replace some of the wetland area originally lost to development, but these restoration opportunities pose unique challenges due to the agricultural legacy of the soil. Understanding how wetlands restored on agricultural lands develop and function is critical not only for improving restoration practice, but for developing our ecological understanding of wetlands. In New England, cranberry farming has dominated the agricultural industry for over a century, but decreases in yield, increases in costs, and competition from more productive cultivars grown primarily in the upper Midwest and Canada are forcing many New England cranberry farms to close. Because most cranberry farms developed in the late 1800's and 1900's are located in low-elevation coastal bogs in densely populated areas, the potential of restoring wetland functions lost to agricultural development is particularly significant. The objective of this study was to assess soil-based ecosystem functions in an actively farmed cranberry bog, a retired cranberry bog, a restored bog, and a natural reference bog that had not been farmed. At each site we measured a suite of soil processes and properties including denitrification potential, soil organic matter, moisture, and microbial biomass as indicators of wetland development and functioning. Denitrification potential increased with increasing soil moisture, organic matter, and microbial biomass. However, all measures were significantly lower in the retired and restored bogs compared to natural wetlands. A trajectory model based on short-term trends suggests that restoration provides a quicker path to wetland development and functional equivalence than site retirement with no restoration, although the process appears to be slow.

1. Introduction

Ecological, social, and economic factors are resulting in increased levels of land abandonment worldwide, particularly that of farmland (Cramer et al., 2007). There are many reasons for ceasing to use land for agriculture, including landscape degradation, shifts in the demand for commodities, population increases and human habitat development, and environmental stressors such as long-term droughts (Cramer and Hobbs, 2007; Rey Benayas et al., 2007). While abandonment of agricultural land can have negative cultural and environmental consequences, it may also have important benefits. In particular, passive revegetation and active ecosystem restoration could improve water regulation, soil recovery, nutrient cycling, and increase biodiversity (Rey Benayas et al., 2007).

Wetland restoration is a particularly significant benefit of farm abandonment in cases where former natural wetlands were drained for crop and pastureland. This is because wetlands provide critical ecosystem services such as nutrient cycling, water quality improvement, water storage and flood abatement, and habitat provision, (Mitsch and Gosselink, 2000; Zedler and Kercher, 2005), and these ecosystem services are lost when wetlands are destroyed (Zedler, 2003). One of the primary goals of wetland restoration in abandoned agricultural land is the restoration of denitrification, where nitrate is removed through microbial reduction to nitrogen gas (Seitzinger et al., 2006; Hey et al., 2012). Denitrification occurs primarily under anaerobic conditions by heterotrophic microbes and generally takes place in saturated soils with high levels of organic carbon (C), which are typical of wetlands. Oxygen diffuses through waterlogged soils at a much lower rate compared to dry soils (Whiting and Chanton, 2001), creating anaerobic conditions that in turn slow decomposition of organic matter and decrease the rate at which carbon dioxide (CO_2) is released into the atmo-

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sphere (Mitsch et al., 2013). In this regard, wetlands are also highly valued for their role in global C storage and sequestration.

The eastern United States became the first region on the planet to experience significant abandonment of cropland from 1870 onward (Cramer and Hobbs, 2007). The rate of agricultural abandonment in New England slowed during the latter half of the twentieth century, and in some areas tracts of abandoned land are being returned to agriculture. With climate forecasts projecting that the Northeast will be a relatively water-sure region, this trend could continue and perhaps accelerate (IPCC, 2014). However one type of agriculture that is only beginning to leave the Northeast is cranberry, *Vaccinium macrocarpon*, farming.

The cranberry industry has dominated southeastern Massachusetts for over a century, but domestic prices for cranberries have fallen in recent decades, driven by increased production in Canada and the upper Midwest where land is more readily available (USDA NASS, 2014). This has forced domestic cranberry growers to increase their hectarage in order to remain profitable, something that is more easily done in states such as Wisconsin where land is plentiful. However, few additional hectares are available for farming in southeastern Massachusetts due to existing residential and industrial coastal development. Century-old farms in Massachusetts are also likely to have lower yields per hectare than newer farms in the Midwest and Canada because they use older cultivars that produce less fruit than new hybrid varieties, and their often irregular spatial layout, established on the outlines of former peat bogs, is not well suited to mechanized cultivation and harvesting. With several thousand hectares of cranberry farms in southeastern Massachusetts facing abandonment, in this study referred to as retirement, landowners are left holding altered landscapes that contain legacy impacts of a century of intensive management (MA Department of Agricultural Resources, 2016).

Cranberries in southeastern Massachusetts are traditionally farmed in kettle hole bogs originally formed from glacial deposits during the last Ice Age. They are adapted to the relative lack of fertility in this sandy environment, preferring soils that are acidic and contain low soil organic matter. When grown for large-scale agriculture, cranberry farmers add 4–8 centimeters of sand on their bogs approximately every three years to stimulate shoot growth and promote decomposition of soil organic matter. The sand layer also buries leaf drop and insect pests, and allows for improved soil drainage and increased aeration at the vine roots to counteract the poorly drained soils typical of wetland environments. Cranberry farms engineer hydrology using water control structures to regulate the amount, duration, and direction of water flow within the bog. Drainage ditches and bypass channels are constructed to divert water away from the bog surface and lower the water table in the farmed cells (Sandler and DeMoranville, 2008). Chemical pesticides, herbicides, insecticides, and fertilizers are applied between late May and early August (Averill et al., 2008).

Massachusetts cranberry farms are often in densely populated low-elevation coastal areas, locations that have significant climate change and environmental implications. In particular, reconnecting these historic wetlands to coastal waters could have implications for storm surge protection, blue carbon storage, fish passage, and wildlife habitat. In contrast, farm retirement without restoration would take the bog out of production and end intensive management practices such as sand addition, but the landscape would retain its drainage ditch network, water control structures, and other hydrologic alterations. While the potential impact of wetland restoration of low elevation coastal retired cranberry farms is significant due to their special location, these systems may be uniquely challenging to restore due to extensive hydrologic manipulation and an approximately one meter anthropogenic soil layer from long-term sand additions and application of pesticides, herbicides, insecticides, and fertilizers.

Two cranberry bog restorations have been completed in Massachusetts to date, and this is the first study to examine the development of their soil properties and associated wetland functions. Soil properties and processes can serve as excellent indicators of ecosystem function in wetlands, as these functions predominantly depend on interactions between its soil and water (Richardson and Vepraskas, 2000). However, studies have shown that soils in restored wetlands are slow to develop and function at a lower capacity compared to natural wetlands for decades if not centuries after restoration (Craft et al., 2002; Bruland et al., 2003; Ballantine and Schneider, 2009; Ballantine et al., 2014). With thousands of hectares of cranberry farmland in Massachusetts eligible for restoration in the coming decade, there is a need for scientists, restoration practitioners, land owners, and land managers to better understand how these unique systems may develop following retirement versus restoration.

The objective of this study was to compare the impact of farmland retirement versus restoration on wetland development and function. Specifically, we compared actively farmed, retired, and restored cranberry bogs with natural reference bogs to understand effects on ecosystem functions that are largely driven by hydrology and soil condition, including denitrification potential, soil organic matter, moisture, and microbial biomass. We predicted that these measures would vary with site treatment (active, retired, restored, natural), and that retired and restored bogs would have higher levels of soil-based ecosystem functioning than actively farmed cranberry bogs, but would not have reached the levels of natural reference bogs three years after restoration.

2. Material and methods

2.1. Study area and site descriptions

To compare the impact of cranberry farm retirement versus restoration on wetland development and function, we selected four sites near Plymouth, MA: an active cranberry farm, a retired but not yet restored cranberry farm, a restored wetland that was historically used as a cranberry farm, and a natural bog. Together, these sites represent a progressive sequence of freshwater wetland restoration, ranging from bogs completely unrestored and frequently disturbed by agriculture to a nearby natural reference wetland that restoration projects may model.

The actively farmed site, Rocky Pond Bog, is part of the University of Massachusetts Cranberry Station (41.883°N, 70.696°W). The 1.6-ha bog is a for-profit farm actively managed to research sustainable practices for cranberry farming in the region. The bog is wet harvested in the fall and periodically left flooded over the winter months so that vines are frozen and protected from excess damage. Sand layers are generally added over the surface of the ice after flooding to allow for even distribution throughout the bog area as the ice melts. The floodwater is drained in early spring and farmers typically apply chemical pesticides and fertilizers between late May and early August.

The retired site is part of Tidmarsh Farms, a 234-ha private farm that had been maintained as a commercial cranberry bog for over 100 years (41.911°N, 70.568°W). Farming operations slowed in the early 2000s, and, in 2010, a permanent conservation easement was placed on 78 ha of cranberry bogs and wetlands through the NRCS Wetlands Reserve Program. In cooperation with the Massachusetts Department of Fish and Game Division of Ecological Restoration and other partners, property owners are carrying out comprehensive ecological restoration actions to restore hydrology to support self-sustaining wetlands on site. The restoration proposal targets three common legacy impacts from cranberry farming that affect hydrology in the watershed: presence of an anthropogenic sand