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Assessing constructed wetland functional success using diel changes in dissolved oxygen, pH, and temperature in submerged, emergent, and open-water habitats in the Beaver Creek Wetlands Complex, Kentucky (USA)

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ABSTRACT

We assessed the functional success of restored wetlands by determining if the patterns in dissolved oxygen (DO), temperature, and pH were similar to those conditions observed in natural wetlands. The Beaver Creek Wetlands Complex consists of dozens of marshes and ponds built in a former Licking River floodplain, in the hills of east Kentucky, USA. In natural wetland ecosystems, aquatic primary production is highest in emergent and submerged vegetations zones; where daybreak dissolved oxygen (DO) is often near zero, and DO may rise to well over 100% saturation past mid-day. Open-water areas, dominated by phytoplankton, have less dramatic diel DO fluctuations—often without pre-dawn anoxia. Compared to open water, temperatures fluctuate less dramatically in vascular vegetation, due to shading and suppression of wind and waves. Measurements of ecosystem metabolism (diel changes in DO and pH) in three aquatic habitats of the constructed wetlands (emergent vegetation, submerged vegetation, open water) were compared to these natural ideals. In Beaver Creek Wetlands, water temperature patterns were not as dramatic as in natural habitats, nor did they did follow a similar trend. Waters in emergent vegetation (29.5 °C) were warmest; submerged vegetation coolest (26.5 °C); open-water intermediate (27.4 °C). Diel DO and pH patterns were not similar to natural habitats. Highest net primary production (NPP) and gross primary production (GPP) were measured in emergent vegetation waters (mean GPP = 7.58 g m^{-2} d^{-1}); lowest in submerged vegetation (mean GPP = 5.48 g m^{-2} d^{-1}); and intermediate in open-water (mean GPP = 6.95 g $m^{-2}d^{-1}$). Diel pH changes were greatest in the highly productive emergent waters (median maximum daily difference of 0.36), and not as pronounced in submerged vegetation and open-water (median maximum change = 0.16 and 0.22, respectively). Water-column respiration was generally about double NPP. Like natural ecosystems, near anoxic DO concentrations were consistently measured in emergent and submerged plants before dawn; whereas open-water zones were generally >4 mg l^{-1}. These restored wetland systems may need more time to be functionally equivalent to natural marshes.

1. Introduction

It is useful to compare the performance of a constructed or engineered system to their natural counterparts to assess restoration success, energy flow, or nutrient dynamics (Mitsch, 1995). Although many wetland assessment methods determine function by proxy from structure (including plant, soil, and animal community assessments), reliable and accurate measurements of whole-system functions are essential for ecological engineers to make management decisions, or determine if a wetland is meeting functional goals (Mitsch, 1995). For example, a site may have been planted with the specified number of trees per unit area, and survival may meet statutory criteria; however, the wetland may not be sequestering carbon at rates comparable to a natural wetland, or supporting reproducing populations of common species. Wetland self-design is an emergent property that is not measured with small-scale or structural criteria (Mitsch and Jørgensen, 2004).

Wetland metabolism is defined by profound daily fluctuations in pH and dissolved oxygen (DO). Compared to deepwater ecosystems, wetlands have more profound diel changes in water temperature. These temperature variations are affected by aquatic macrophytes. Since a wetland landscape may contain emergent vegetation, submerged vascular plants, and open water plankton, as well as epiphytes, periphyton, and benthic algae, isolated measurements of a particular portion of the primary producer community is problematic, and may not take into account cybernetic

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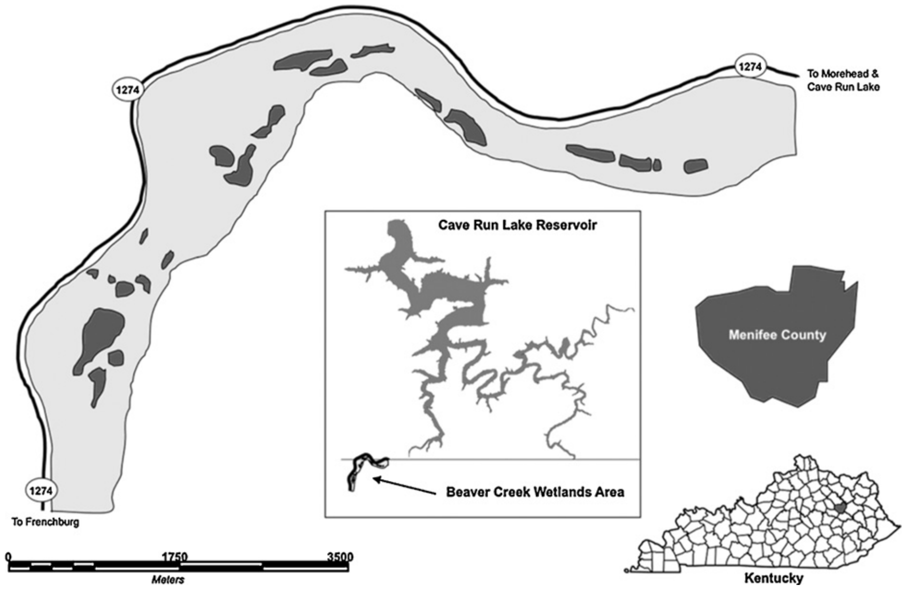

Fig. 1. Location of the Beaver Creek Wetlands Complex in Kentucky, USA.

feedbacks between these components. The diverse autotroph complex in wetlands is probably best assessed with a method, such as diel oxygen change, that takes into account the dynamics of the whole system acting in concert.

Diel measurements of in aquatic ecosystems once involved numerous tedious sample collections and analyses by a large team taking shifts, or by some sleep-deprived individuals. Greater reliability and availability of recording datasondes have made it easier to collect diel short time-scale measurements of oxygen, temperature, and pH, without a series of "all night" sampling. Accordingly, there is increased interest in whole system metabolism measurements pioneered by H.T. Odum (Odum, 1956; Odum and Odum, 1955; Odum and Hoskins, 1958) which were codified in Hall and Moll (1975), and have been reviewed by Mitsch and Day (2004). In deeper lakes ecosystems, modifications of Welch's (1968), and Odum and Hoskins' (1958) calculations are being perfected to examine daily oxygen mass balances (Gelda and Effler, 2002; Van de Bogert et al., 2007).

Wetlands are ideal ecosystems for assessment of ecosystem production with whole-system metabolism measurements (Reeder and Binion, 2001). Researchers have examined the effects of shallow water vegetation and high concentrations of phytoplankton on oxygen dynamics in a variety of systems. Diel changes in temperature, oxygen, and pH have been measured in different portions of restored or constructed wetlands to assess ecosystem functions at the Des Plains River near Chicago, USA (Fennessy et al., 1994), in the Everglades Restoration as part of a pre-assessment (Chimney et al., 2006), at the Olentangy River Restoration wetlands research area in Columbus, OH, USA (Liptak, 2000), to determine function and energy flow in lakes (Fontaine and Ewel, 1981; Mitsch and Kaltenborn, 1980; Van de Bogert et al., 2007) and to assess cypress dome sewage treatment (Dierberg and Brezonik, 1983).

Our research set out to examine diel fluctuations of temperature, oxygen, and pH in restored wetlands in the Licking River basin of east Kentucky, adjacent to Cave Run Lake reservoir. Previous studies showed these wetlands met jurisdictional criteria for success, and have plants and animals characteristic of wetland ecosystems (Haight and Reeder, 1997; Kenawell and Reeder, 2002; Reeder and Caudill, 2000). Our objective was to determine if diel changes in submerse vegetation, open-water, and emergent vegetation communities in these restored wetlands mimicked patterns found in natural wetlands.

2. Materials and methods

2.1. Site description

The Beaver Creek Wetlands Complex is located in northeastern Kentucky in Daniel Boone National Forest (Fig. 1). The watershed of the study area is dominated by mixed-mesophytic forest in sparsely populated regions of Rowan, Bath and Menifee counties near Cave Run Lake. Our sites are located on restored floodplains of former rivers and streams, drowned to by damming to create Cave Run Lake reservoir. Most the wetlands were constructed over a decade ago. Beaver Creek, a tributary of the Licking River, is located south of Cave Run Lake reservoir and runs parallel to many of the wetlands. Details of wetland construction techniques are available in Biebinghauser (2007). Wooded slopes surround the wetlands on the upland side while approximately 22 ha of planted wildlife food (corn, grass, clover, and wheat) have been developed on the western portion of the complex.

East Kentucky's hills are not historically a region with extensive wetland area. Wetlands tended to be located on hillside seeps, or along riparian bottomlands. Seeps were often destroyed for resource extraction; most rich bottomlands were cherished for their agricultural potential. Wetland ponds monitored in this study were restored in a region where historic hydrologic patterns of the floodplain have been destroyed, and replaced by a human managed system. Cave Run Lake dam, a US Army Corps of Engineers control structure, generally lowers water levels a couple meters in Fall to reach "winter pool", and then allows the lake to collect spring flood waters to bring the lake up to "summer pool". Water control is not necessarily managed just for the local region, but also as part of the Ohio River basin's, and Mississippi River basin's, hydrologic management demands.

Hydrologic modifications and human control that does not match natural climatic forcing are not uncommon difficulties in wetland restoration for ecological engineers seeking to restore wetland functions in a region. To compensate for the lack of natural seasonal flooding patterns, most these wetlands were constructed