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Physical wetland characteristics influence amphibian community composition differently in constructed wetlands and natural wetlands

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ABSTRACT

Wetlands provide critical habitat for a diverse group of organisms and provide important ecosystem services. Despite this, most natural wetlands have been lost to anthropogenic activities, and as a result, wetland construction is common mitigation practice. Therefore, examination of constructed wetland viability in replacing the function of lost wetlands is vital. Our primary objectives were to compare amphibian communities of shallow and deep constructed wetlands to natural wetlands and to identify which wetland characteristics affect species composition. All wetlands were hydrologically isolated and fishless; natural wetlands had an ephemeral hydrology, and constructed wetland hydrology varied from ephemeral to permanent. Overall, constructed wetlands did not sufficiently replicate natural wetlands with respect to the amphibian community. However, two of our constructed wetlands had a drying period and exhibited communities more similar to natural wetlands. Hydroperiod and canopy closure were indicators of amphibian community composition. Many species observed in natural wetlands were rare in shallow constructed and absent in deep constructed wetlands. Additionally, dominant predator species (primarily *Lithobates catesbeianus*, *Lithobates clamitans*, and *Notophthalmus viridescens*) associated with permanent water were more abundant in constructed wetlands. Water depth, pH, and emergent vegetation were lower in natural wetlands. These data influenced land managers to revise construction methods and to renovate deep constructed wetlands by creating gradual slopes, decreasing maximum depth to 20 cm or less, maintaining canopy cover, and decreasing soil compaction to attempt replication of natural wetland hydrology.

1. Introduction

Wetland loss is a global phenomenon; in fact, Myers (1997) suggests a worldwide wetland loss of 50% within the last century. In the United States, many states have lost a large percentage of historical wetlands. For example, Kentucky sustained a loss of 81% of its historic wetlands (512,332 ha) between 1780 and 1980, with much of this being attributable to conversion of wetlands for agriculture (Dahl 1990, 2000). Additionally, human alteration of wetland hydrology (e.g., deepening an ephemeral pool for cattle watering purposes) can change the natural community composition (Kingsford et al., 2004; Havel et al., 2005; Foti et al., 2012), which can be detrimental for species that have life-history traits specific to ephemeral wetlands (Kiesecker et al., 2001; Pechmann et al., 2001; Jenkins et al., 2005; Denton and Richter 2013; Calhoun et al., 2014). Habitat loss and alteration are two of the most important factors affecting persistence of amphibian communities in the US and worldwide (Becker et al., 2007; Gallant et al., 2007).

Because of the high rate of wetland loss over the last century, it has become routine to mitigate for these losses by constructing wetlands. Brown et al. (2012) synthesized the literature (37 peer-reviewed articles) on amphibian communities utilizing restored, newly constructed, and mitigated wetland sites. Presumably due to the lack of natural reference sites, only 16 of these studies on constructed wetlands used natural reference wetlands as a comparison. Most of the research observed differences in amphibian use of constructed and natural wetlands based primarily on wetland hydrology and presence of fish predators (Petranka et al., 2007). For example, Pechmann et al. (2001) found ephemeral natural wetlands had more salamander species present than permanent constructed wetlands. Additionally, Denton and Richter (2013) found constructed wetlands intended to be ephemeral were mostly permanent and did not support specialist amphibians of the

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ephemeral natural wetlands. These studies demonstrate the difficulty of replicating natural habitats when attempting to mitigate or create habitat for amphibians.

The composition and fitness of amphibian communities found within wetlands is influenced by multiple interacting factors including water quality (pH- Freda and Dunson 1986; Rowe et al., 1992; Grant and Licht 1993; Bunnell and Zampella 1999; McCoy and Harris 2003; salinity- Smith et al., 2007; Karraker et al., 2008; dissolved oxygen- McIntyre and McCollum 2000; Skelly et al., 2002; Schiesari 2006), hydroperiod (Snodgrass et al., 2000b; Eagan and Paton 2004; Baldwin et al., 2006; Ryan 2007), slope (Shulse et al., 2012), canopy closure (Skelly et al., 2002; Thurgate and Pechmann 2007; Denton and Richter 2013), aquatic vegetation (Eagan and Paton 2004; Shulse et al., 2010, 2012), predation (Werner 1986; Werner and McPeek 1994; Knutson et al., 2004; Petranka et al., 2007; Shulse et al., 2010, 2012), and competition (Werner et al., 1995; Shulse et al., 2012). Hydroperiod, in particular, has influential effects on multiple wetland characteristics and consequently species composition within wetland habitats (Wellborn et al., 1996; Korfel et al., 2010; reviewed in Calhoun et al., 2014). While wetlands with a long hydroperiod tend to have higher species richness (Babbitt et al., 2003), wetlands with a short hydroperiod tend to have less common, specialized species (Snodgrass et al., 2000b; Korfel et al., 2010). A short hydroperiod can be beneficial in excluding dominant amphibian predators (e.g. *Lithobates catesbeianus*, American bullfrogs) (Kiesecker et al., 2001), increasing water temperature, and influencing development and survival of larvae to metamorphosis (Rowe and Dunson 1995; Wellborn et al., 1996; Skelly et al., 2002). Thus, ephemeral wetlands with short hydroperiods are important for maintaining biological diversity (Snodgrass et al., 2000b; Calhoun et al., 2014). However, there is a risk of tadpole mortality during long periods of low precipitation within these temporary habitats (Rowe and Dunson 1995; Seigel et al., 2006).

Wetland design for non-game wildlife, specifically amphibians, is a burgeoning field of study (Petranka et al., 2007; Biebighauser, 2011; Shulse et al., 2012; Denton and Richter 2013; Calhoun et al., 2014). Wetland building for game species (e.g. deer, turkey, etc.) has a long tradition in wildlife management (Leopold 1987). Historically, these wetlands functioned as "all-purpose" permanent water sources (often stocked with fish) with wide variability in design; usually consisting of deep, steep-sided wetlands constructed by deepening an existing wetland or constructing a large clay-based groundwater dam (Biebighauser, 2007, 2011). Conversely, sensitive amphibian species tend to thrive in complex habitats with shallow littoral zones for basking and predator avoidance (Porej and Hetherington 2005; Shulse et al., 2012; Denton and Richter 2013), woody debris and emergent vegetation for egg attachment (Shulse et al., 2010, 2012), and have species dependent tree canopy specifications (Skelly et al., 2002; Thurgate and Pechmann 2007; Denton and Richter 2013). Previous research on constructed wetlands as amphibian habitat has frequently addressed species richness or presence as an indicator of success (Knutson et al., 2004; Balcombe et al., 2005; Canals et al., 2011; Bellakhal et al., 2014) rather than focusing on replication of natural amphibian community structure as a gauge of success.

There were two primary objectives of this research: (1) to examine whether or not constructed wetlands foster amphibian community composition comparable to amphibian communities occupying natural ephemeral wetlands and (2) to determine what wetland characteristics affect species composition. In particular, this study focused on wetland characteristics with potential management implications including dimensions, depth, hydroperiod, canopy closure, aquatic vegetation, and water chemistry. Identification and quantification of specific characteristics that differ between natural and constructed wetlands are important information for land managers for improvement of current constructed habitats and for success of future amphibian enhancement projects.

2. Material and methods

2.1. Study sites

Wetlands have been constructed by the U.S. Forest Service in the Daniel Boone National Forest (DBNF), Kentucky, USA for over 50 years, with hundreds constructed since 1988 for the purpose of wildlife habitat enhancement (T. Biebighauser, pers. comm.). The wetlands used as study sites for this project consisted of ridge-top constructed and natural wetlands located within the Cumberland Ranger District of the DBNF in the Western Allegheny Plateau ecoregion (Woods et al., 2002). All of the study wetlands were hydrologically isolated ephemeral, semi-permanent, or permanent fishless wetlands located on ridge tops. We selected 14 study wetlands including 5 natural ephemeral (all known to exist), 5 shallow (2 ephemeral, 3 permanent) constructed wetlands (minimum depth <20 cm), and 4 permanent deep constructed wetlands (minimum depth >20 cm) for sampling in 2010 (Fig. 1) based on preliminary data on water depths (see Drayer, 2011). The study wetlands ranged in size from a surface area of 44.6–1415.6 m^2 (median = 351.9 m^2).

2.2. Sampling: amphibians

During the spring and summer 2010, we surveyed each wetland for amphibians in two-day increments in consecutive one-month intervals for a total of four sampling periods. Sampling commenced in May and ended in August. Each amphibian wetland survey included a perimeter visual encounter survey, aural survey, aquatic minnow trapping, and dipnetting (Crump and Scott 1994; Scott and Woodward 1994). Visual and aural encounter surveys started upon arrival at the wetland and consisted of walking the perimeter of the wetland while recording adults, juveniles, larvae, and egg masses observed. We deployed three collapsible mesh minnow traps along the perimeter of each wetland and distributed them evenly among heterogeneous habitat types. As the ephemeral wetlands decreased in size, we decreased the number of traps we placed in them. The traps were checked for amphibians within 24 h, and all species were recorded. Before dipnetting, a compass was used to separate the wetland into quadrants following the cardinal directions, north, south, east, and west from the geographic center of the wetland. For each 1400 m^2 (surface area), 20 one-meter dipnet sweeps (split evenly between the four sections) were performed. The number of dipnet sweeps was scaled up or down based on the estimated size of the wetland during each sampling. All habitat types (e.g., emergent vegetation, floating vegetation, and open water) were sampled evenly.

2.3. Sampling: physical wetland characteristics

To understand which factors within natural and constructed wetlands potentially affect amphibian community composition, the following variables were measured (at each wetland): wetland size, percent aquatic vegetation, water quality, depth at one meter from shoreline, maximum water depth, minimum water depth, and canopy closure. All variables were measured each sampling period except for percent canopy closure. Percent canopy closure was measured at maximum leaf-out and was estimated with a spherical densiometer at each of the four cardinal directions (from the geographic center of the wetland) along the perimeter and one point directly above the geometric center of each wetland. A meter stick was affixed in the deepest part of the wetland to record maximum and minimum depth measurements. Minimum depth refers