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Geomorphology, habitat, and spatial location influences on fish and macroinvertebrate communities in modified channels of an agriculturally-dominated watershed in Ohio, USA

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ABSTRACT

We evaluated relationships between in-stream habitat, spatial distribution, and geomorphic features at 28 study sites within a predominantly agricultural watershed in Ohio. Objectives were to: (1) measure and compare the physical structure and biotic communities of highly modified drainage channels to those of minimally impacted channels, (2) identify significant environmental factors influencing fish and invertebrate assemblages in modified channels, and (3) relate them to biotic communities in a multivariate statistical model and then to compare fish species and macroinvertebrate taxa models to common multi-metric bioassessment index models. We used canonical correspondence analysis (CCA) and variance partitioning to relate environmental variables to fish and macroinvertebrate community attributes. Geomorphically, minimally impacted sites were statistically different than bench and trapezoidal sites. Bench sites were statistically different than trapezoidal sites in floodplain width and depth ratios indicating that bench formation provided some amount of attached floodplain for the inset channel and functioned more similar to how natural streams would function. Key ecological drivers for macroinvertebrate communities were stream size, gradient and connectivity to a floodplain. Key ecological drivers for fish communities were quality of in-stream habitat variables; however, stream size and connectivity to a floodplain also were important. Larger, perennial sites tended to support more aquatic biota and more diverse assemblages either as primary habitat or as conduits between higher quality upstream or downstream locations. The latter can be critical to sustaining biota in highly modified agricultural watersheds. In smaller systems, in-stream habitat was a limiting factor but, more importantly, they experienced smaller discharges and can become intermittent during dry months. We hypothesized that leaving vegetated benches in the agricultural ditch would improve local ecology, but our data do not support this hypothesis as measured benches were either intermittent or too small to be important fluvial features. In the agriculturally-dominated modified headwater systems studied, we hypothesize that the proximity to a nearby patch of high quality habitat might be the main driving factor.

1. Introduction

Smedma et al. (2004) reported that 33% of the world's cropland requires surface or subsurface drainage. The Midwest Region of the United States is one of the most productive agricultural regions of the world. Subsurface drainage is ubiquitous due to widespread areas of poorly drained soils. The Midwest Region also serves as the headwaters to important receiving systems such as the Gulf of Mexico and Great Lakes. Current and historical modifications to surface and subsurface water systems and land uses have had

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direct impacts on downstream receiving systems including chronic hypoxia and harmful algal blooms that threaten ecology, the economy, and human health (Mitsch, 1991; Mitsch et al., 2001; Turner and Rabalais, 2003; Blann et al., 2009). Jaynes et al. (2010) estimated that drainage water management practices could be used on about 25 million hectares in the region.

Subsurface drainage systems rely on open channels, often called ditches, which have been constructed to a trapezoidal shape to efficiently drain the soil profile and facilitate the flow of water away from the field. In Ohio alone, approximately half of all cropland has been altered by some type of artificial drainage (e.g., surface ditches, subsurface tile lines, or sub-irrigation), and there are more than 32,000 km of modified open channels that facilitate land drainage (Wooten and Jones, 1955). Straightened trapezoidal channels are often built wider and deeper than nature would have intended. This results in increased sedimentation during low flow events and increased bank erosion during high flow events (Rhoads and Herricks, 1996; Jayakaran et al., 2005; Jayakaran and Ward, 2007). Ecologically, these channels lose the habitat structure and complexity necessary to support diverse aquatic biota (Frothingham et al., 2002; Blann et al., 2009). Habitat loss resulting from channelization and maintenance is considered to be a major control of local fish assemblage characteristics in agricultural systems (Rhoads and Herricks, 1996; Frothingham et al., 2001, 2002; Smiley et al., 2008; Rhoads and Massey, 2011). In Ohio streams, channel modification continues to be a primary impairment to aquatic life use attainment (OEPA, 2006).

Some ditches and modified channels that are not maintained or 'cleaned out' recover by forming benches and a small inset channel in the bottom of the ditch through fluvial and sediment transport processes (Rhoads et al., 1999; Frothingham et al., 2002; Landwehr and Rhoads, 2003; Jayakaran et al., 2005; Rhoads and Massey, 2011). Multiple studies have been completed on the process of bench formation in agricultural channels and the relationship of channel shape to sediment and nutrient transport (Kuhnle et al., 1999; Landwehr and Rhoads, 2003; Jayakaran et al., 2005; Powell, 2006; Ward et al., 2008). Natural and constructed bench development in agricultural ditches provides an environment that might improve the ecological function of highly modified channels while maintaining drainage capacity (Jayakaran et al., 2010; Roley et al., 2012a,b).

Historically, few studies focused on the impact of agricultural drainage practices on fish and macroinvertebrate populations. More recently, however, agricultural ditches and modified channels have been recognized as supporting diverse populations of aquatic organisms. Although less complex than natural stream systems, multiple studies have found that in-stream habitat is an important determinant of fish and macroinvertebrate community structure in channelized agricultural streams (Davies et al., 2008; Herzon and Helenius, 2008; Smiley et al., 2008; Janssen and Allan, 2008; Colvin et al., 2009; D'Ambrosio et al., 2009; Smiley and Gillespie, 2010; Crail et al., 2011; Simon and Travis, 2011; Rhoads and Massey, 2011; Leslie et al., 2012; Magner et al., 2012).

Leslie and colleagues (2012) have suggested that the management of drainage ditches to improve water quality (see Needelman et al., 2007; Evans et al., 2007; Smiley et al., 2008; Blann et al., 2009) may provide the potential to improve habitat for aquatic biota. Studies have shown that evaluation and management of aquatic biota, especially macroinvertebrates, may be best-suited at the patch scale in highly disturbed watersheds (Townsend, 1989; Wilson, 1994; Palmer and Poff, 1997; Dole-Olivier et al., 1997; McCabe and Gotelli, 2000; Winemiller et al., 2010). In these watersheds, places of refugia or undisturbed patches and their proximity to disturbed patches may be important sources for re-colonization following disturbance (Palmer et al., 1995; Townsend et al., 1997; Stanley et al., 2010).

We present one part of a U.S. Environmental Protection Agency Regional Environmental Monitoring and Assessment Program study that evaluated the ecological functioning of headwater drainage channels in a highly modified agricultural landscape. Three separate objectives were addressed. The first objective was to measure and then to compare biotic communities and the environmental characteristics of fluvial geomorphic dimensions, in-stream habitat and spatial location of highly modified drainage channels to those of minimally impacted streams. The second objective was to identify the most significant environmental variables that influenced fishes and macroinvertebrates in our study sites. The third objective was to use the most significant environmental variables and relate them to biotic communities in a multivariate statistical model and then to compare fish species and macroinvertebrate taxa models to common multi-metric bioassessment index models. The unique aspect of this study, compared to previous studies by us and others, was that the experimental design focused on the influence of small floodplains (called benches) on biotic communities within highly modified and agricultural drainage channels.

2. Materials and methods

2.1. Site selection

The project focused on an agriculturally dominated region in Ohio, USA, within the 1114 km^2 Upper Olentangy River watershed (OEPA, 2006; Hydrologic Unit Code #05060001; Fig. 1). The river flows southwesterly through a low gradient landscape (0.08% slope). Primary land use throughout the watershed is agriculture (82%). More than 80% of the cropland is used for corn and soybean production with lesser amounts of wheat, small grain, and hay (OSU, 2006). The Upper Olentangy River watershed contains 16% forest and 1.3% surface water systems and wetlands. It receives an average of 927 mm of rainfall annually (OSU, 2006). The soils predominantly are sandy clay loams with low infiltration rates. Much of the agricultural land has subsurface drainage.

D'Ambrosio et al. (2009) found that stream size was an important factor explaining fish assemblage variation in the Olentangy River watershed. Based on those results, we revisited the Upper Olentangy River watershed with a new experimental design to further elucidate the impacts of agricultural land use and headwater channel modification on aquatic biota. In 2006, data were obtained at 11 non-randomly selected sites where we had conducted prior studies (D'Ambrosio et al., 2009; Witter, 2006). In 2007, we obtained data from 17 new randomly-selected sites and re-sampled the 11 non-randomly selected sites (Fig. 1). In the current study, we limited our study site size to less than 50 km^2 to evaluate only headwater channels. We sampled macroinvertebrates along with fishes to investigate if key environmental drivers differed between the two groups.

2.2. Experimental design and data collection

All of the study sites had experienced some degree of past modification. To distinguish between most impacted and least impacted channels, each study site was visually classified as being in one of the three experimental groups: (1) no bench development (e.g., trapezoidal one-stage channels); (2) natural bench development and no regular maintenance (e.g., recovering from past channelization); and (3) stream-like conditions (e.g., minimally impacted, meandering channels). Eight sites were classified as