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The Influence of Channelization on Fish Communities in an Agricultural Coldwater Stream System

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ABSTRACT.—We characterized coldwater stream fish community response to habitat degradation and channelization for agriculture. Coldwater streams are not common in the lower midwestern United States, and these streams differ from warmwater streams with respect to their diversity and community response to degradation. Six sites were sampled on the coldwater Mac-o-chee Creek in Ohio. Three reaches were classified as geomorphically constrained (by a roadway) and three as recovering (unconstrained and not channelized or cleaned for more than 100 y). Within each reach 31 mesohabitat units were sampled and were delineated as riffles, runs, or pools. Our goals were: (1) to examine how habitat and geomorphic impairment influences the abundance and community structure of coldwater fishes; and (2) to test whether the constraints on recovery from channelization were more influential in structuring communities than mesohabitat types. Our hypothesis was that we would find lower species diversity overall in the recovering sites because they would be more indicative of a coldwater fauna. In contrast, we hypothesized that the sites that are not able to recover (geomorphically constrained) would be more indicative of a warmwater fauna, and thus more diverse. We found lower species abundances, diversity, and species richness in recovering stream reaches than impaired reaches. Mesohabitat types present are influenced by channelization and recovery but are also largely a product of geomorphologic setting of the study streams. The effects of habitat degradation on the biota and the resulting trophic structure are important for designing restoration targets for coldwater systems, which may be naturally less diverse than warmwater counterparts. For example, biometric scores like Index of Biotic Integrity (IBI) are often used as restoration targets, but this would be inappropriate unless a coldwater-specific IBI were used.

INTRODUCTION

Biota in fluvial systems are influenced by physical and chemical parameters as well as by the geographic and geological history of the systems that they inhabit (Allan, 1995; Poff, 1997; Williams *et al.*, 2003). The environmental factors that shape a stream system are hierarchical in nature-from watershed, to reach, to microhabitat scale (Poff, 1997).

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Researchers have tested how hierarchical characteristics shape the way channel form influences habitat and fish communities (Schlosser, 1991; Smiley and Dibble, 2005; Parsons and Thoms, 2007). Landscape-scale features (*e.g.*, geology, climate) structure reach-scale features like riffle-pool morphology and hydrology, which in turn structures fish communities (Frissell *et al.*, 1986). Studies have confirmed that mesohabitat units (riffles, runs, and pools) in a stream are directly impacted by channel form and will support distinct biotic communities (Gorman and Karr, 1978; Beisel *et al.*, 1998; Taylor, 2000). As habitat changes occur in lotic systems, mesohabitat units can become altered resulting in changes to natural aquatic communities, which are dependent on a less disturbed state of the stream system (Davies and Jackson, 2006).

Anthropogenic modification of stream channels to accommodate agricultural landuse is widespread in the United States and has led to changes in the types and amounts of mesohabitats within streams. When European settlers first encountered the fertile, relatively flat lands of the lower midwestern (defined here as Ohio, Indiana, Illinois, and Iowa) United States, many regions contained stream systems that regularly flooded interconnected wetland complexes (Schumm *et al.*, 1984; Dameron-Hager, 2004). Early inhabitants converted large areas of these wetland complexes to agricultural fields by modifying existing streams and dredging new drainage channels, which have persisted in many areas. Wetland drainage and channel straightening caused geomorphic changes in stream systems that were well beyond the rate of change that would have occurred without human influence, and many of the headwater streams in the lower midwest have been channelized (Urban and Rhoads, 2003). The results of these changes across large areas of the lower midwest have included the loss of connectivity to floodplains, channel over-widening, increased bank erosion and sedimentation, decreased sinuosity, non-point source nutrient input, increased temperatures associated with riparian removal and stream widening, and loss of instream habitat heterogeneity (Richards *et al.*, 1993; Yoder and Rankin, 1995; Stanford *et al.*, 1996; D'Ambrosio *et al.*, 2009).

Coldwater stream systems in the lower midwest are not common and are often surrounded by and connected to warmwater systems that differ geologically and support different biota. Most research on coldwater streams in the region has focused on trout dominated streams in the upper midwest, such as Wisconsin, Michigan, and Minnesota (Lyons *et al.*, 1996; Mundahl and Simon, 1998; Wehrly *et al.*, 2003). Historically salmonid-free, coldwater systems in the lower midwest are now often stocked with exotic brown trout (*Salmo trutta*), rainbow trout (*Onchorhynchus mykiss*), or brook trout (*Salvelinus frontinalis*), which are not native to Ohio River systems (Trautman, 1981).

It has been demonstrated that increased heterogeneity and quality of instream habitat leads to increases in the abundance and diversity of biota in warmwater streams (Gorman and Karr, 1978; Palmer and Poff, 1997; Vadas and Orth, 2000; Lau *et al.*, 2006). However, pristine coldwater streams generally have unique community attributes including lower diversity, lower species richness, and higher proportions of intolerant species than their warmwater counterparts. As coldwater streams undergo limited to moderate degradation, species richness and diversity of fish tends to increase (Lyons *et al.*, 1996). The physical changes in habitat that occur can alter the thermal regime and make these coldwater systems more suitable to warmwater fish colonization (Lyons *et al.*, 1996).

The objective of this study was to examine how channelization and geomorphic constraints on recovery result in changes to mesohabitats, and subsequently fish communities of a coldwater stream ecosystem. We hypothesized that geomorphically constrained sites would differ in their mesohabitats resulting in more tolerant, warmwater

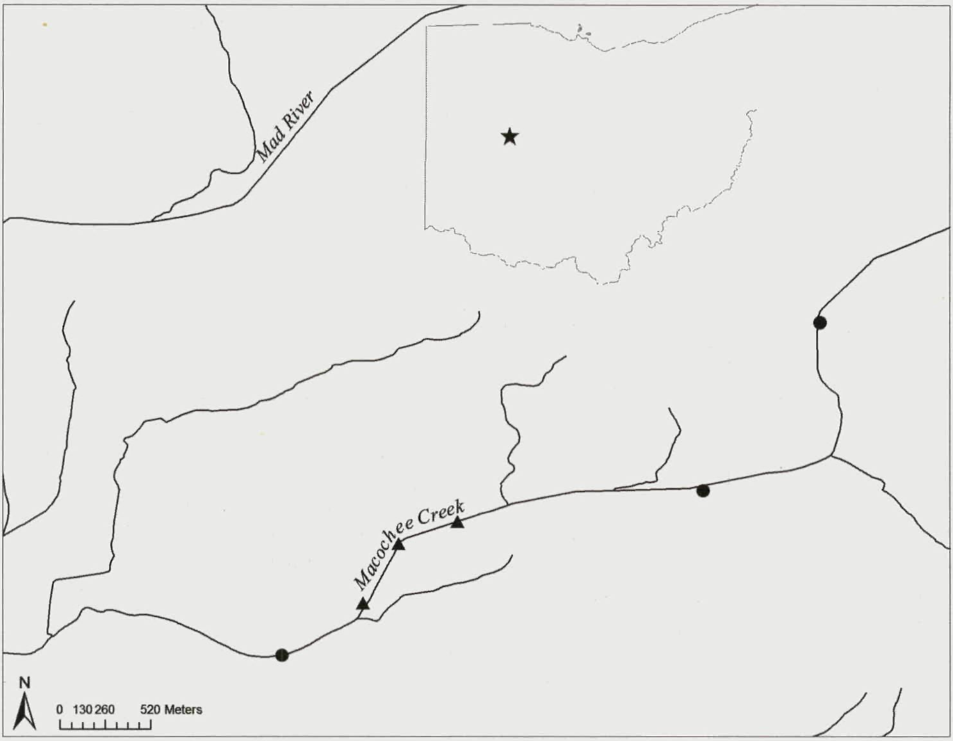

FIG. 1.—Location of Mac-o-chee Creek and its watershed within Logan County, Ohio. Inset identifies the location within the state of Ohio. Constrained sites indicated by a 'triangle' and recovering sites indicated by a 'circle'

species than the geomorphically recovering sites. We predict geomorphically constrained sites will have simpler geomorphology (*i.e.*, run habitat replacing riffle/pool morphology); thus, recovering reaches should have deeper, more permanent pools, and more well developed riffles.

METHODS

STUDY AREA

Mac-o-chee Creek drains a watershed area of 53 km^2, and is located in west-central Ohio (Fig. 1). The watershed consists of 76% agricultural landuse (row crop and pasture) and 24% second growth mixed forestland (Gorney *et al.*, 2011). Over the past two centuries, the stream has served as a mill power source, an agricultural drainage way, and, most recently, as a recreational fishery. In many ways, it is representative of the history of stream management in Ohio (Trautman, 1981). The gradient of the system near the mouth, where this study was conducted, is very low (1–3%) as the stream enters a relatively flat valley at its confluence with the Mad River. Most of the lower end of the stream system was channelized approximately 100 y ago for agricultural drainage and the construction of a state highway. Currently, the state highway is prohibiting the natural recovery of the channel and its connection to an active floodplain in a section of the creek.

The retreat of the Laurentide ice sheet during the Wisconsin period created vast till and outwash deposits across northern Ohio, Indiana, Illinois, and Iowa. Glacial melt waters that cut through glacial till layers in end moraines created deep river valleys that are often characterized by abundant groundwater entering surface stream channels (Koltun, 1995). The input of groundwater to Mac-o-chee Creek results in consistent base flow hydrology in summer months, with an average summer temperature of 20 C (OEPA, 2005). The stream has received a coldwater use designation by the Ohio Environmental Protection Agency (OEPA, 2005).

SITE SELECTION AND HABITAT MEASUREMENTS

Six study reaches, each 150 m in length, were selected for this study. Study reaches were a minimum of 375 m apart (average distance 814 m, range 376–1632 m). Based on visual assessment classification by Ohio Department of Natural Resources (D. Mecklenberg, Ohio DNR, pers. comm.), three reaches were classified *a priori* as geomorphically constrained and three as recovering (unconstrained). Geomorphically constrained reaches were located close to a road that has contributed to degraded conditions by preventing channel migration. We observed the lack of channel unit development, presence of artificial side channel pools formed by riprap, and lack of riparian canopy cover in the constrained sites. In addition, constrained reached included long runs and a few short riffles with side channel pools and large pieces of concrete and limestone riprap forming the primary substrate. Unconstrained reaches were bordered on both banks by riparian corridors of varying widths (range 33–65 m). They were characterized by the presence of clear building features within the channel such as active gravel bars, the narrowing of the channel in riffle areas, and the presence of pools formed by scour downstream of large wood, logjams, or tree roots at meander curves. Riffles were fast flowing and abundant in the unconstrained reaches. Within each of the six study reaches, mesohabitat units were delineated as riffle, run, or pool using a visual classification method (Rabeni *et al.*, 2002), resulting in the identification of 31 mesohabitat units.

To validate our classification and to quantify habitat among sites, a Qualitative Habitat Evaluation Index (QHEI) and canopy cover were measured at the reach scale. The QHEI is a habitat index calculated by visual assessment of substrate composition, instream cover, channel quality, riparian and bank stability, pool/riffle/run development, and gradient (OEPA, 1987). The QHEI, has been shown to be an effective tool to detect trends in habitat impairment (Moerke and Lamberti, 2003; Lau *et al.*, 2006). Canopy cover was measured using a hand held densiometer at three systematically spaced transects along the thalweg of each reach (every 50 m). All other habitat measurements were determined for each mesohabitat unit. Stream velocity (m/s) and depth (m) were measured along 2 to 3 transects (depending on the length) within each mesohabitat unit using a Marsh-McBirney Flowmate and depth rod. Transects were located perpendicular to flow, and a minimum of four equidistant points were measured along each transect. Wetted width was measured at each transect, and the length of each mesohabitat unit was measured.

FISH SAMPLING

Fishes were sampled in each mesohabitat unit via electroshocking with a generator-powered long line, with a pulsed DC current, mounted on a small, towable boat (OEPA, 1987). Block nets were placed at the upstream and downstream ends of each mesohabitat unit prior to shocking. Each mesohabitat unit was shocked with 2 to 3 passes, until no new species were collected. All fish were identified and enumerated on site and immediately returned to the stream. All sampling was conducted from Jul. to Aug. 2007.

DATA ANALYSIS

We conducted an Analysis of Variance (ANOVA) to compare QHEI and canopy among constrained versus recovering sites. We used a Two-way ANOVA to test how transect-scale habitat data (*i.e.*, depth, velocity, wet width, and mesohabitat length) differed with respect to constrained versus unconstrained reaches and among mesohabitat types.

Extremely rare species (comprising less than 0.01% of total abundance, or only present in one mesohabitat unit sample) were removed from the dataset. Shannon's evenness, species richness, total abundance, and Shannon diversity index were calculated from the species × site abundance data using PC-ORD 5.0 for Windows (McCune and Mefford, 1999). We also calculated feeding and general tolerance metrics after Lyons *et al.* (1996) and OEPA (1987). Fish were assigned to one of five feeding guilds: invertivore, herbivore, top carnivore, generalist, or filter feeder. Each fish species also was designated as tolerant, intolerant, or undetermined. We calculated the percent individuals of each feeding and tolerance guild for each mesohabitat unit (OEPA, 1987). The percent individuals that were simple lithophils were calculated for each mesohabitat as well because these species are sensitive to silt accumulation and substrate quality (Poff and Allan, 1995). Temperature preferences play an important role for fish dispersal in coldwater stream systems; therefore, the percent coldwater obligate fish at each mesohabitat unit also was calculated with temperature preference data for each species (Lyons *et al.*, 1996).

Direct gradient analysis was used to interpret how aspects of fish community structure interact with measured environmental variables. A detrended canonical correspondence analysis (DCCA) was conducted using CANOCO with the environmental and fish datasets to determine the appropriate ordination technique. The gradient length suggested that the relationships among the explanatory variables were linear so redundancy analysis (RDA) was selected for ordination (ter Braak and Prentice, 2004). RDA is a multivariate direct gradient analysis technique that incorporates multiple dependent variables at once (ter Braak and Prentice, 2004). Two separate RDAs were conducted; one using fish abundance data and the other using calculated metrics. We were testing how species composition is correlated with physical habitat, and also how suites of community metrics are correlated with habitat. For each RDA, a Monte Carlo test with 500 permutations was conducted using CANOCO on all canonical axes to determine if the ordination diagram was significantly different than one that could have occurred by chance alone. Nominal variables, in this case Riffle, Run, Pool, Impairment, and Recovery, were coded as dummy variables and are represented in the ordination diagrams by an "X" at the centroid of the sample scores belonging to that class (ter Braak and Smilauer, 2002).

RESULTS

HABITAT MEASUREMENTS

The QHEI indicated that constrained sites (55.1) had significantly reduced habitat quality compared to recovering sites (76.3; ANOVA $P = 0.024$). Canopy cover was greater in recovering sites (81 versus 14; ANOVA $P = 0.001$) where intact wooded areas were present on both banks.

Width and length were not significantly different between constrained and recovering reaches or by mesohabitat. There was a significant difference in velocity and depth in the two-way ANOVA (constrained*mesohabitat $P < 0.0001$; mesohabitat $P < 0.0001$). Thus, at least for these two variables, we confirmed our original hypothesis that geomorphically constrained sites would differ in their mesohabitat structure from recovering sites. Pools in

TABLE 1.—Mean value (±standard deviation) of mesohabitat unit measurements

Unit type	N	Current velocity (m/s)	Water depth (m)	Wetted width (m)	Mesohabitat length (m)
Riffle					
Constrained	4	0.71 (0.15)	0.12 (0.05)	7.38 (1.50)	14.23 (4.48)
Recovering	7	0.57 (0.13)	0.10 (0.03)	7.35 (2.18)	16.76 (7.04)
All	11	0.62 (0.15)	0.11 (0.03)	7.36 (1.84)	15.74 (6.00)
Run					
Constrained	7	0.21 (0.07)	0.36 (0.13)	7.55 (1.5)	34.89 (28.1)
Recovering	6	0.27 (0.12)	0.30 (0.07)	6.62 (1.5)	17.76 (8.7)
All	13	0.24 (0.10)	0.33 (0.11)	7.12 (1.5)	28.66 (8.7)
Pool					
Constrained	3	0.11 (0.06)	0.76 (0.28)	6.73 (0.55)	19.45 (3.23)
Recovering	4	0.09 (0.06)	0.84 (0.30)	6.46 (1.11)	25.10 (9.36)
All	7	0.10 (0.06)	0.80 (0.27)	6.58 (0.86)	23.22 (7.96)
All Constrained	14	0.33 (027)	0.38 (0.27)	7.33 (1.29)	26.15 (22.4)
All Recovering	17	0.34 (0.22)	0.36 (0.33)	6.86 (1.66)	19.43 (8.41)

constrained reaches were confined to the lateral part of the channel and the primary substrate in these pools was riprap, boulders, and other artificial material introduced into the stream for bank stabilization. Pools in recovering reaches were deeper and generally longer than constrained reaches. They were located at rootwads, channel curves, or logjams and stretched across the width of the channel (Table 1). Riffles in recovering reaches were generally longer than in constrained reaches and were often bordered by in-channel point bars (Table 1).

FISH COMMUNITY STRUCTURE

There were 9514 fishes collected from 19 species in seven families. Seven abundant fish species (mottled sculpin, creek chub, blacknose dace, white sucker, rainbow darter, silver shiner, and central stoneroller; for scientific names, Table 2) comprised 98% of the total fish abundance. Mottled sculpins made up 54% of the total abundance across all samples and were dominant in all riffle mesohabitats, in which they comprised 92% of the fish abundance. Three individuals of a state threatened species, the tonguetied minnow, were also captured. One very rare species, the striped shiner, (comprising $<0.001\%$ of the total collection) was deleted from further analysis. The greatest numbers of fish were collected in constrained reaches and runs.

FISH COMMUNITY-HABITAT RELATIONSHIPS

The fish abundance RDA (Fig. 2) identified a significant relationship between fish abundance and environmental variables ($P = 0.004$). The first two RDA axes accounted for 95.3% of the explained variation (Eigenvalue Axis 1 = 0.378, Axis 2 = 0.064). On the first RDA axis, creek chub and white sucker species scores were associated positively with water depth and pools (Fig. 2). Many of the rare species, such as tonguetied minnow, fantail darters, and green sunfish, were strongly associated with current velocity and wetted-width, indicating these species were more associated with geomorphically recovering sites. Many of these species were associated with riffle mesohabitats. The first axis was much stronger and is associated with a gradient of mesohabitat conditions. The second axis, which explained

TABLE 2.—Relative Fish Abundance (RA) across 31 mesohabitat units sampled. Trophic groups are defined as: GEN = Generalist, INV = Invertivore, CARN = Top carnivore, HERB = Herbivore, FILT = Filter feeder. Tolerant (TOL) or Intolerant (INTOL) classification is listed for the appropriate species. Blanks for tolerance indicate species that have intermediate tolerance values

Family/Species names unconstrained	Common name (RDA Code)	Trophic group	Tolerance	RA Constrained	RA
Catostomidae					
Catostomus commersoni	White sucker (WHSU)	GEN	TOL	0.1025	0.0936
Hypentelium nigricans	Nothern hog sucker (HOSU)	INV	INTOL	0.0009	0.0017
Centrarchidae					
Lepomis cyanellus	Green sunfish (GRSU)	GEN	TOL	0.0002	0.0005
Lepomis macrochirus	Bluegill (BLSU)	INV	TOL	0.0002	0.0007
Micropterus salmoides	Largemouth bass (LABA)	CARN		0.0041	0.0002
Cottidae					
Cottus bairdi	Mottled sculpin (SCUL)	INV		0.5219	0.6137
Cyprinidae					
Campostoma anomalum	Central stoneroller (CEST)	HERB		0.0135	0.0251
Exoglossum laurae	Tonguetied minnow (TOMI)	INV	INTOL	0.0002	0.0005
Luxilus chrysocephalus	Striped shiner (STSH)		INV	0.0002	0.0000
Notropis photogenis	Silver shiner (SISH)	INV	INTOL	0.0167	0.0127
Phoxinus erythrogaster	Southern redbelly dace (SRBD)	HERB		0.0000	0.0007
Rhinichthys atratulus	Blacknose dace (BLDA)	GEN	TOL	0.0755	0.0718
Ricardsonius balteatus	Red side dace (REDA)	INV	INTOL	0.0013	0.0043
Semotilus atromaculatus	Creek chub (CRCH)	GEN	TOL	0.2334	0.1213
Petromyzontidae					
Lampetra lamottei	American brook lamprey (BRLA)	FILT	INTOL	0.0084	0.0153
Percidae					
Etheostoma caeruleum	Rainbow darter (RADA)	INV	INTOL	0.0163	0.0321
Etheostoma flabellare	Barred fantail darter (FADA)	INV		0.0000	0.0005
Salmonidae					
Salmo trutta	Brown trout (BRTR)	CARN		0.0047	0.0053

much less variation, was associated with our classification of sites as constrained or recovering.

The RDA using different community metrics was not significant with the Monte Carlo test ($P = 0.21$). Thus, there was not a strong relationship between any of the community metrics and mesohabitats or degree of geomorphic constraint.

DISCUSSION

The results of this study indicate that fish communities in Mac-o-chee Creek were structured more by the degree of mesohabitat development than by whether or not the stream was constrained geomorphically. However, geomorphic constraint did have an impact on current velocity and water depth, which would in turn affect mesohabitat development. We were expecting to see a greater separation between constrained sites that had simplified mesohabitat structure and sites that were recovering geomorphically and were developing

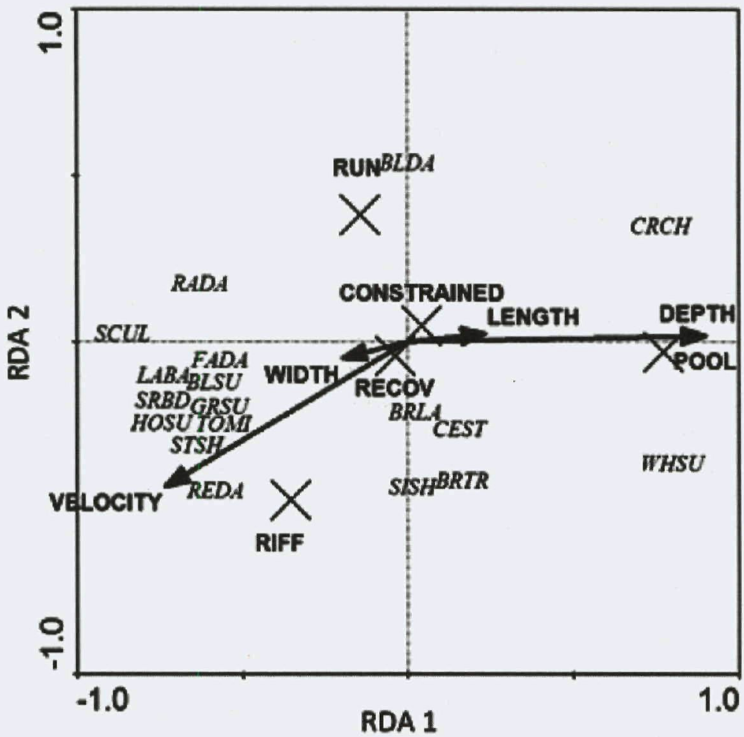

FIG. 2.—Redundancy Analysis (RDA) ordination of environmental variables and fish abundance. Nominal environmental variables are expressed as the centroid of the sample score of that variable. Species codes are listed in Table 2

an active floodplain. Many of the recovering sites were developing two-stage channel morphology (Ward and Trimble, 2004), such that benches were beginning to form even within dredged, trapezoidal shaped channels. As the benches form, natural sinuosity within the channel begins to develop and some water quality improvements may be observed (Landwehr and Rhoads, 2003;Ward and Trimble, 2004). Even the most constrained sites in Mac-o-chee Creek still had a coldwater community dominated by mottled sculpin.

Most of the variation in the fish community structure was related to mesohabitat classification. Riffle mesohabitat units were dominated by benthic invertivorous fish (*e.g.,* rainbow and fantail darters) that prefer riffle habitats and are less tolerant of habitat degradation (Trautman, 1981). It is likely that riffles were historically more common in channelized sections than they are today. Tolerant, eurythermal, generalist fish dominated pool units. These species likely colonized Mac-o-chee Creek from its parent stream, the Mad River. Prior to agricultural conversion of the landscape in this region, tolerant pioneering species such as white sucker and creek chub were probably not as abundant in coldwater headwater streams (Trautman, 1981). High suspended sediment levels, from altered geomorphology, coupled with low gradient allow these more generalist fish species to colonize and thrive.

Redundancy analysis using different metrics as a surrogate for species was not statistically significant. This result was not surprising as metrics like diversity indices result in a loss of much information. These types of metrics take more complex species abundance-by-site matrices and collapse information for simplicity (Williams *et al.*, 2003; Pyron *et al.*, 2011).

We did not find evidence that more degraded sites (geomorphically constrained) would have a warmwater stream community. This is in contrast to our original predictions, based on the literature (Lyons *et al.*, 1996). These results are not consistent with the commonly accepted principle that higher quality habitat will lead to greater species diversity, richness, and abundance (Lepori *et al.*, 2005; Smiley and Dibble, 2005; Sullivan *et al.*, 2006; Syrkanen and Muotka, 2007). Many multi-metric indices for fish and invertebrates generally award higher integrity scores for communities with more species and higher abundance. For this reason, warmwater indices are often inappropriate for detecting trends of degradation in coldwater stream systems (Lyons *et al.*, 1996; Hughes, 2004). Positive correlations between physical (geomorphological or habitat) and ecological assessment scores for stream reaches are cited as confirmation of the effectiveness of these indices (Lammert and Allan, 1999; Weigel *et al.*, 2003; Sullivan *et al.*, 2004). Biological integrity and habitat diversity are not necessarily equal surrogates in all systems (Davies and Jackson, 2006).

This research did not conclusively determine a fish response to disturbance in a coldwater stream ecosystem that was part of an agricultural watershed. These watersheds in the lower midwest are exposed to a complex variety of stressors that can be chemical, physical, or hydrological in nature. Such stressors have changed substantially in the recent past as our ability to conduct agriculture on a large scale has increased (Watzin and McIntosh, 1999). It is likely that all six of our sites have been recovering since the last channelization event, and there are few barriers to fish movement in Mac-o-chee Creek. As a result, we did not observe much difference among the sites. Future studies should consider including more than one stream, but the difficulty in replicating this study is the lack of these types of coldwater streams in the lower midwest in close proximity. Even more limited are pristine sites that could be used as a control.

Recent efforts have focused on the importance of restoring biological integrity to impacted stream reaches. Stream restoration is routinely conducted on small, reach-scale patches at great cost per stream length (Alexander and Allan, 2006). Therefore, a better understanding of small-scale fluctuations in the distribution of stream biota is important until watershed scale restoration projects are more widely implemented. Since the time of this study, an expensive restoration project was conducted in a relatively small piece of the constrained portion of Mac-o-chee Creek to restore sinuosity and riparian function. It would be interesting to repeat this study, as our results would suggest the restoration likely would have little impact on the fish community. Most likely, the barrier that historically protected this low-gradient coldwater fish community from invasion was the temperature of the water (Trautman, 1981). Restoration and revegetation of the riparian floodplain is likely to provide the best conservation protection for these types of coldwater systems.

As watershed scale approaches to improving water quality increase in importance, assessment and monitoring techniques need to be refined for unique systems such as coldwater streams (Lyons *et al.*, 1996). Surprisingly little is known about coldwater streams in the lower midwest. Additionally, if climate change increases global temperatures, coldwater stream systems have the potential to undergo drastic change (Rahel *et al.*, 1996). Species-poor communities are rarely recognized as being of high conservation value (Lyons *et al.*, 1996), but in agricultural areas, where nutrient input is a common stressor these communities may be increasingly threatened (Watzin and McIntosh, 1999). If water quality improvement and stream restoration are to improve in effectiveness, then new management and monitoring strategies need to be developed for protecting coldwater streams in the lower midwestern United States.

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