MICROHABITAT SELECTION AMONG FIVE CONGENERIC DARTER SPECIES IN INDIANA RIVER AND STREAM ECOSYSTEMS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF SCIENCE

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MUNCIE, INDIANA

JULY 2010

Microhabitat Selection among Five Congeneric Darter Species in two Indiana Watersheds

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ABSTRACT. Five *Etheostoma* darter species including the greenside darter (*E. blennioides*), rainbow darter (*E. caeruleum*), fantail darter (*E. flabellare*), johnny darter (*E. nigrum*), and orangethroat darter (*E. spectabile*) were collected from seven streams and rivers in two Indiana watersheds to determine patterns of microhabitat selection with respect to depth, water velocity (flow), and substrate size. Greenside and rainbow darters were most commonly found among intermediate substrate sizes (cobble-boulder) and locations with higher velocities and greater depths. Fantail and orangethroat darters associated with intermediate to large substrate sizes (cobble-bedrock) in shallower average depths and lower velocities. Fantail darters were only observed in the Whitewater River watershed. In contrast, johnny darters were observed only within the Upper White River watershed among small substrate sizes (silt-sand), moderate velocities, and increased depths. Substrate size was the most important variable in characterizing microhabitat selection as shown using nonmetric multidimensional scaling (NMS) and multinomial logistic regression. Patterns of microhabitat use are likely influenced by competition, morphology and other life history traits, and may explain the existence of congeneric species in ecosystems having heterogeneous habitats. Ultimately, these segregational patterns, whether

induced by spatial or resource-based competition, allow for the coexistence of benthic fish species.

INTRODUCTION

The group of fishes commonly known as darters is a highly diverse assemblage of benthic stream vertebrates. The genus *Etheostoma* is the most diverse group of darters (Page and Burr, 1991) in North America, many of which occur sympatrically in localized benthic communities (Etiner and Starnes, 1993; Knouft, 2003). These species are benthic insectivores (Adamson and Wissing, 1977; Schlosser and Toth, 1984) rarely exceeding 8 cm in total length (Trautman, 1981; Pflieger, 1997). Despite their relatively small size, darters have been shown to be important in structuring stream communities (Winn, 1958) and can be indicators of stream diversity and integrity (Simon and Lyons, 1995). A number of studies have been directed at diet (Forbes, 1880; Turner, 1921; Mathur, 1973; Adamson and Wissing, 1977; Cordes and Page, 1980), microhabitat use (Paine *et al.,* 1982; Chipps *et al.,* 1994; Kessler *et al.,* 1995; Stauffer *et al.,* 1996; Welsh and Perry, 1998), and other life history characters such as resource partitioning and morphology (Schoener, 1974; Schlosser and Toth, 1984; Guill *et al.,* 2003). However, limited information exists on patterns of microhabitat use within Midwestern streams where species diversity and abundance is typically lower (Kuehne and Barbour, 1983; Page, 1983) when compared to Appalachia (Chipps *et al.,* 1994; Stauffer *et al.,* 1996; Welsh and Perry, 1998; Skyfield and Grossman, 2008) and large portions of the southeastern United States (Henry and Grossman, 2008). Ecological interactions among stream assemblages, particularly with species in the genus *Etheostoma*, have been of long importance to researchers in the effort to understand the complexities involved in maintaining a sustainable and healthy ecosystem.

Defining the subtleties of microhabitat use by darters will enhance our understanding of negative anthropogenic impacts, leading to protection or enhancement of these habitats and fishes (Rosenfeld, 2003). This is particularly true in Indiana and parts of the Midwest, as a plethora of streams and their riparian corridors have been physically altered (*e.g.*, channelized or cleared) in association with agricultural needs (Gammon, 1998; Hortle and Lake, 1983; Poff *et al.* 1997). Moreover, published information on Indiana streams has focused on stream development and degradation (Lau *et al.*, 2005; Moerke and Lamberti, 2004), rather than organismal ecology, such as habitat use by aquatic life (Cain *et al.*, 2008). Because *Etheostoma* darters are benthic, they may provide a better glimpse into the negative impacts of habitat modification and degradation associated with depth, water velocity (*i.e.*, flow), and substrate. For example, coarse substrate may provide cover, foraging areas, and spawning grounds for lithophilic species, like many darters, but substrates effectively become destroyed by siltation and sedimentation, clogging the interstitial areas where these behaviors typically occur (Bain, 1999). Therefore, an absence or decline of these species could indicate some form of degradation has occurred, suggesting a need to implement protection or restoration activities.

Habitat selection on any scale contributes to construction of aquatic and terrestrial communities, laying the foundation of all ecological interactions among species and overall community dynamic (Resetarits, 2005). There are various theories behind habitat selection in sympatric darter species with most emphasis on competitive interactions (both intra- and inter-specific; Schoener, 1974), morphological features (Guill *et al.*, 2003; Knouft, 2003), predator avoidance (Taylor, 1996), and those of a dynamic nature such as flow regime, temperature, and disturbance (Menge and Sutherland, 1976; Schlosser and Toth, 1984). Few have addressed patterns of microhabitat use across regions that are known to differ in habitat availability and heterogeneity (Welsh and Perry, 1998). Therefore, the objectives of this study were to define microhabitat use of sympatric darter species found in two distinct watersheds and determine which microhabitat-use variables (depth, flow, and substrate composition) were most influential in segregating species. In addition, we evaluated whether habitat differences between watersheds were driving factors in darter habitat selection.

METHODS

Study sites— Fishes and discharge were collected/measured from nine sites on seven streams/rivers in the Upper White River (Delaware County) and Whitewater River (Franklin County) watersheds, Indiana (Fig.1). Study sites were chosen on accessibility and the distributional range of five abundant darter species (Page, 1983): greenside darter (*E. blennioides*), rainbow darter (*E. caeruleum*), fantail darter (*E. flabellare*), johnny darter (*E. nigrum*), and orangethroat darter (*E. spectabile*). Land use and ecoregion type differed between the watersheds (Homoya *et al.*, 1985). Streams selected within the Upper White River watershed were influenced by agriculture, channelization, and urbanization, and composed primarily of long runs with few riffles and pools. Streams chosen in the Whitewater River watershed were primarily surrounded by forested or field riparian areas, providing more extensive instream cover, and were minimally influenced by agriculture and channelization, typically retaining their natural sinuosity and character. All streams sampled (Table 1) were classified (Horton, 1945) as 1^{st} or 2^{nd} order, with the exception of the White River (4^{th} order). Sampling took place during average to below daily median flow volumes as measured by the nearest United States Geological Survey real-time stream flow gauging stations.

Fish collection—Darters were collected from July to mid-September 2008 using standard backpack dc electrofishing (Smith-Root Model LR-24, Vancouver WA). Collection length in each stream was 15 times the wetted width of the stream and included at least one riffle, run, and pool segment. The location of a darter collected was marked using color-coded weights corresponding to each species (N = 5) during electrofishing. Each weight was affixed with a 20 cm portion of nylon string so that weights could easily be found. These instream markers denoted the exact stream location of individual fish collections for subsequent microhabitat assessment. All fishes were identified and enumerated.

Habitat analysis— To characterize general habitat characteristics and surrounding land use at each sample site, an assessment using the Qualitative Habitat Evaluation Index (QHEI) (Rankin, 1989) was performed. This assessment differentiated stream habitat characteristics among sites, specifically substrate, that aided in the explanation of darter microhabitat use. Although the QHEI is a composite score for habitat quality, the individual metrics have also been correlated to use and selection by fish taxa (Cain *et al.* 2008).

We measured stream discharge (cm/s) and width (m) prior to fish sampling. Current velocity (flow) was measured using an analog flow meter (Model 201 Portable Water Current Meter, Marsh-McBirney) at 60% of the total depth (McMahon, *et al.*, 1996) with depth measurements taken using a staff marked in centimeters.

Following electrofishing, we measured flow (m/s), depth (m), and % substrate size at each darter collection location. Darters can be found within the interstitial regions and crevices created by aggregations of larger substrate types and obtaining accurate measurements of flow in these areas can prove difficult (Stauffer *et al.*, 1996). To address this issue and standardize the collection effort, flow measurements were taken approximately 3 cm above the substrate. Substrate composition was measured using a 1x1-m square PVC pipe frame centered over each colored marker to visually observe percentages of available substrate size classes (Chipps *et al.*, 1994). A modified Wentworth Scale (Cummins, 1962) was used in this study as size classes of substrate were visually estimated on site and included: silt (< 1 mm), sand (> 1-3 mm), gravel (> 3-20 mm), cobble (> 20-250 mm), boulder (> 250-1000 mm), and bedrock (> 1000 mm-embedded layers) (Greenberg, 1991). Darter location relative to the substrate (on top, within, or beneath) was not recorded as electrofishing likely disturbed their initial vertical positioning.

Statistical Analysis—Habitat features at each site based on QHEI metrics were compared using Principal Components Analysis (PCA; Minitab version 15). Only the first three components with Eigen values greater than one were reported. Analysis of variance (ANOVA) and Tukey-Kramer multiple comparison tests were performed on each PCA axis to further explain habitat structure. Microhabitat use among the five species and variables important in segregation were determined using nonmetric multidimensional scaling (NMS) multivariate analysis (PC-ORD; McCune and Grace, 2002). This non-parametric ordination procedure iteratively finds a solution so that the distances of data points reflect the ranking order of the data (Holland, 2008). ANOVA and Tukey-Kramer multiple comparisons was used as a post-hoc analysis of each NMS axis. Percent substrate was arcsine-square-root transformed prior to the analysis and α = 0.05 was used for all analyses.

A third analysis, multinomial logistic regression (MLR) related patterns of darter microhabitat use to a reference category (MLR; SPSS version 16). In this test, habitat use by orangethroat, fantail, rainbow, and johnny darters were individually compared to greenside darters, the reference category. Greenside darters were chosen as the reference category as they were found in both watersheds and were highest in abundance. The multinomial logistic regression generates a slope that indicates the direction and strength of the relationship between the reference category and its comparisons. For example, if a species generated a positive slope relationship to the greenside darter based on flow, it would suggest this species is associated with higher flow. A significant negative slope would imply the test species would be associated with lower flow. The greenside darter was compared to the other four species on all three microhabitat variables for a total of 12 comparisons.

RESULTS

A total of 278 darters was collected from the nine sites in 2008 (Table 2). Greenside and rainbow darters were highest in abundance (N = 95 and 88, respectively), and were collected in both watersheds. Orangethroat darters occurred in both watersheds, but in low abundance (*N* = 31). The least abundant fish (*N* = 23) were fantail darters, collected only in the Whitewater River watershed while johnny darters were also low in abundance (*N* = 41) and only collected in the Upper White River watershed. There were no sites during the sampling period in which all five study species were present. Other *Etheostoma* and *Percina* species, such as the banded darter (*E. zonale*), blackside darter (*P. maculata*), and logperch (*P. caprodes*), were occasionally collected but were in low abundance and not included in analyses. Non-darter species occurring in high abundance at sites were creek chub, *Semotilus atromaculatus*, blacknose dace, *Rhinichthys obtusus*, bluntnose minnow, *Pimephales notatus*, white sucker, *Catostomus commersoni*, and green sunfish, *Lepomis cyanellus*.

Habitat differences by watershed — The QHEI scores ranged from 51-71 within the Upper White River watershed, (fair-excellent), while in the Whitewater River watershed scores ranged from 78-85 (excellent) (Ohio EPA, 2006). Sites located in the Upper White River watershed were characterized by a higher gradient and higher pool/glide quality (more pools/glides). In contrast, Whitewater River watershed streams were characterized by increased instream cover, a greater range of substrate types, and more stable riparian zones and channels (Figures 2 and 3). However, only loadings of the PC1 axis were significantly different between the watersheds (ANOVA: $F_{1,7} = 10.38$, $P = 0.015$). The Whitewater River watershed was characterized by higher percentages (Table 3) of the "best types" category of substrate (ANOVA: $F_{1,7} = 5.73$, $P = 0.048$) and streams with a more natural channel morphologies (ANOVA: $F_{1,7} = 26.81$, $P < 0.001$). While sites in the Upper White River watershed were characterized by increased silt/sand and were negatively influenced by channelization effects than sites in the Whitewater River watershed, the two watersheds contained similar dominant substrates (cobble-bedrock); although in varying amounts.

The six QHEI substrate sub-categories also varied between watersheds. Greater percentages of cobble and gravel were found in the Whitewater River watershed, while the Upper White River watershed had increased percentages of sand (Table 4). Boulder and bedrock substrates were present in streams of both watersheds; however, these were the primary substrates of Harvey's Branch located in the Whitewater River watershed. The predominant substrates of steams in the Whitewater River watershed were larger, with little sand or silt (Table 1).

Microhabitat selection by species—In general, all species selected specific microhabitat types, based primarily on substrate type. The NMS analysis resulted in a final stress of 11.0 using a total of three dimensions, which was significantly lower than the stress level generated by 20 Monte Carlo randomizations (P = 0.48). The NMS ordination of the first two axes resulted in species on the right side of NMS1 to be characterized by medium-sized substrates, such as cobble, and differed from the other species on the left, who were characterized by larger (bedrock) and smaller (sand) substrate types (ANOVA: $F_{4,273} = 7.5$, $P < 0.001$; NMS1) (Fig. 4). Specifically, greenside, orangethroat, and rainbow darters were characterized by cobble-boulder substrates, fantail darters by bedrock, and johnny darters by sand. The second NMS axis resulted in the separation of fantail and johnny darters, where fantail darters were characterized by larger substrates than johnny darters (ANOVA: $F_{4,273} = 14.4$, $P < 0.001$; NMS2) (Fig. 4). A second NMS ordination, including a third axis (NMS3), also resulted in the separation of the fantail from the johnny darter based on substrate size (ANOVA: $F_{4, 273} = 6.2$, P <0.001; NMS3) (Fig. 5).

In the Upper White River watershed, the NMS ordination of the first two axes resulted in species (greenside and rainbow darters) on the bottom to be characterized by cobble-bedrock substrate while those on the top (johnny and orangethroat) to be characterized by sand-cobble substrate. (ANOVA: $F_{3,207} = 17.2$, $P < 0.001$; NMS2) (Fig.6). Johnny darters were also characterized by more silt and greater depths than the remaining species. In the Whitewater River watershed, rainbow darters, found mostly on the top of NMS2 (Fig. 7), were characterized by higher current velocity and greater water depth than the remaining species (ANOVA: $F_{3,63} = 3.4$, $P = 0.03$; NMS2). Fantail darters were also characterized by larger substrates in the Whitewater River watershed than the remaining species.

Greenside, orangethroat, and rainbow darters occurred in both watersheds and showed similar preferences for substrate selection. A NMS ordination of the first two axes resulted in low separation of species found in both watersheds (Fig. 8). All three species were characterized by similar substrates, regardless of watershed. For example, the rainbow darter was characterized by cobble at sites in the Upper White River watershed and the Whitewater River watershed counties.

Lastly, when the greenside darter was used as the "standard" in the multinomial regression analysis, the remaining four darters showed differing habitat selection patterns (Table 5). All four species preferred decreased current velocity (negative slope). Fantail and orangethroat darters additionally preferred shallower water depth when compared to greenside darters (negative slope) while rainbow and johnny darters water depth preference did not differ. Fantail darters occurred with larger sized substrate and johnny darters occurred with smaller sized substrate than greenside darters. Rainbow and orangethroat darters occurred with similar substrate sizes as greenside darters.

DISCUSSION

Our findings demonstrated that microhabitat preferences differed among greenside, johnny, orangethroat, rainbow, and fantail darters. These differences were not individual habitat parameters, but rather, combinations of flow, depth, and substrate. Niche theory suggests that species should separate by at least one microhabitat variable to coexist (Vandermeer, 1972). It was possible to use a single microhabitat parameter (*e.g.*, substrate) to separate two species from each other (*e.g.*, greenside and fantail), but using a single habitat parameter may limit analysis, conclusions, and inference. In addition, the three species that were found in both watersheds (greenside, rainbow, and orangethroat darters) had similar intraspecific microhabitat preferences in both watersheds, suggesting habitat fidelity for individual species, regardless of location. These findings suggest that microhabitat use may largely depend on the presence of congeners, as competition can create habitat displacement of ecologically similar species of darters (White and Aspinwall, 1983). Niche partitioning was evident, with substrate most influential, followed by flow and depth. Flow, depth, and substrate can covary with one another depending on factors such as local hydrology and available sediments which construct substrate composition within a stream (Bain *et al.*, 1988). For example, different patterns of substrate deposition in riffles and pools can create varying depths, creating a correlation between both depth and substrate.

Patterns of overlap in microhabitat use were observed between one or more species and can be explained by several factors. First, during periods of low flow (which was seen at each site), fish have been known to seek out alternate microhabitats to compensate for changes in behavior, competition, and reproduction of sympatric species (Hlohowskyj and Wissing, 1986; Harding *et al.,* 1998). In some cases where drought is severe or in intermittent/ephemeral streams, fish may congregate in pools, where they can become isolated from other species (as in the case of fantail and orangethroat darters in the Whitewater River watershed). Second, species may show high overlap (such as greenside and rainbow darters in both watersheds) simply because of no limitation to habitat. Most of the sites sampled contained the intermediate substrates that contained large amounts of these two species. Lastly, an over-abundance of resources places no threat on another species ability to occupy the same niche (resource sharing), as described by niche overlap (Pianka, 1974).

Segregation was also observed in the study, based primarily on substrate use. Many darter species are dependent upon substrate composition as it provides a means of cover from predation and fluctuations in flow events, as well as foraging and spawning habitat (Schlosser and Toth, 1984; Hlohowskyj and Wissing, 1986; Welsh and Perry, 1998). For instance, both fantail and johnny darters require the undersides of cobbles and boulders to deposit eggs while greenside and rainbow darters scrape food items from the surface of rocks (Winn, 1958). Because *Etheostoma* darters are benthic in nature, they are likely to be highly influenced by the type, availability, and composition of substrate (Hlohowskyj and Wissing, 1986). Taxa that require substrate for feeding or reproduction may partition substrate in a manner so that the stress of competition is reduced. While flow and depth were of minimal influence in segregating these species in this study (most likely due to minimal rainfall), these parameters are of upmost importance in determining how darters partition substrate within the stream community (Englert and Seghers, 1983). In Pipe Creek (Whitewater River watershed), both greenside and fantail darters were found over cobble-boulder substrates. However, greenside darters were located in faster, deeper flows primarily in the middle of riffles while fantail darters were at the base of the riffles where flow and depth were minimal. Similar results were obtained by Wehnes (1973), demonstrating that while substrate may be the basis of microhabitat partitioning, both flow and depth segregate similar species one step further.

Patterns of segregation, like that of overlap, can be explained by several factors. First, darter species may behaviorally segregate from other species, such as for reproduction. All five species in this study possess different methods of reproduction. Greenside darters need vegetation, johnny and fantail darters use the underside of cobbles, and rainbow and orangethroat are egg buriers (Page, 1982). Second, there may be increased competition for food and space, therefore driving out one or more other species to alternate microhabitats (Grossman and Freeman, 1987). Rainbow darters are generally associated with riffle areas among medium-large sized substrates (Page, 1983). However, in Pipe Creek (Whitewater River watershed), the rainbow darter segregated from other species into pools with reduced flow and greater depth, perhaps seeking an alternate microhabitat. Lastly, although only adults were measured in this study, darters and other fish are known to inhabit different microhabitat types based on their life-stage (Page, 1983; Porter and Rosenfeld, 1999). Juveniles typically use different microhabitats than their adult counterparts because of size and differences in feeding.

Although there were differences in microhabitat use between species and species pairs, three species demonstrated habitat fidelity among all sites (where observed). Small stream fishes, like darters, are well known to be habitat specialists (Gorman and Karr, 1978). Greenside, rainbow, and orangethroat darters in this study occupied similar microhabitats despite regional watershed differences and overall habitat complexity. Comparable results have been obtained from other studies testing for microhabitat selection of darters. Chipps et al. (1994) found that the finescale saddled darter (*Etheostoma osburni*) and fantail darter spatially segregated from one another by flow and substrate at one site and separated by flow, substrate, and depth at another, but individual preference for substrate type did not change between sites. A possible explanation to this habitat fidelity shown by the greenside, rainbow, and orangethroat darters in my study is substrate consistency. Minimal changes in flow during this observation period within both watersheds may explain why substrate composition remained consistent, as substrate composition has been known to change from extreme alterations in velocity (Grossman *et al.*, 1995). Silt and sand substrate characterized the Upper White River watershed; however, both watersheds contained similar available substrates. Greenside, rainbow, and orangethroat darters used gravel-boulder (at most sites) in both watersheds. The only exception to this was the orangethroat darter's usage of bedrock at two of the three sites in the Whitewater River watershed, where they had been forced into pools with low flow. From an ecological perspective, species may have used similar microhabitats in both watersheds because there are no immediate threats to their ability to feed and forage.

Although macro-habitat metrics between the two watersheds were different as indicated by the QHEI, the QHEI did not significantly explain differences in microhabitat parameters. This index was developed to explain differences in habitat that fishes use at a reach or stream scale (Rankin, 1989) and it may be too coarse to explain microhabitat differences in flow, depth, and substrate composition (Cain, 2008). However, the QHEI did provide a better understanding of the variation in habitat that was found between the watersheds. Sites sampled in the Upper White River watershed had been subjected to channelization, while those in the Whitewater River watershed retained natural sinuosity. Channelization practices displace fine sediments such as silt and sand and may explain why sites in the Upper White River watershed contained large amounts of these fine substrates in contrast to sites in the Whitewater River watershed. Although the QHEI was not very useful in helping to identify differences in microhabitat, its application to larger scale projects may provide greater insights into stream or watershed management.

Microhabitat selection of the five darters deviate from other published accounts on these species. Greenside and rainbow darters overlapped on substrate use, in contrast to Welsh and Perry (1998), who found these species were spatially segregated in stream run segments, with greenside darters preferring shallower and slower microhabitats composed of larger substrate. One explanation of contradicting results may be the role of seasonality in patterns of microhabitat use, as both greenside and rainbow darters inhabited similar microhabitats in certain months than in others (Stauffer *et al.*, 1996). The analogous use of microhabitat by the greenside and rainbow darters may also be due in part to the extensive distribution and abundance of these species in the Midwest (Kuehne and Barbour, 1983).

Fantail and orangethroat darters exhibited medium-low overlap in microhabitat selection within the Whitewater River watershed. Both of these species differ along many ecological factors including morphology and reproductive/feeding behaviors (Kuehne and Barbour, 1983; Page, 1983). Fantail darters are extremely flexible, typically occupying interstitial regions of intermediate-large substrates for both feeding and depositing eggs (underside of rocks) (Winn, 1958; Page, 1983). In contrast, orangethroat darters have a more rigid body, occupying sand-cobble habitats (Page, 1983). In this study, these species may have been restricted to more upstream portions where flow and depth had diminished and became isolated from other species. Overlap was also recorded for johnny and orangethroat darters in the Upper White River watershed, where both selected sandy substrates (principally at Bell Creek and Killbuck Creek site 2). This is not uncommon, as both species can be found in streams containing high amounts of silt and sand and lowered water quality (Kuehne and Barbour, 1983).

There was an absence of fantail darters in the Upper White River watershed and johnny darters in the Whitewater River watershed. According to distribution maps, these two species share an extensive and overlapping range throughout the Midwest (Gerking, 1945; Kuehne and Barbour, 1983; Page, 1983). Their absence from sites in this study may be explained by each species' strict preference to use specific substrates which were either too low or unavailable at sites within both watersheds. Killbuck Creek sites 1 and 2, Upper White River watershed, contained a high amount (50-100% of available substrate based on QHEI) of sand preferred by that of the johnny darter, while streams in the Whitewater River watershed contained virtually no sandy reaches (< 10%). Johnny darters can be found in the larger, main stem of the Whitewater River Drainage (Gerking, 1945; Brant Fisher, pers. comm., 2010) of Franklin County, Indiana, but may have simply not migrated up into the smaller first order tributaries of this watershed. However, both watersheds contained a suitable amount of cobble-bedrock preferred by the fantail darter. Fantail darters in the Upper White River watershed may have either not existed at the particular sites sampled or were in low abundance due to high embeddedness of substrate and clogging of interstitial regions with sediment/algae where these species are often found (Schlosser and Toth, 1984).

Patterns of segregation of coexisting darters may provide a glimpse into evolutionary processes such as adaptation, migration, and competition. The stable structure of benthic assemblages may be due in part to the ability of many darters to coexist with one another, even when habitat availability and resources are limited. Some of the more ubiquitous *Etheostoma* darter species such as the greenside darter and rainbow darter showed little or no segregation from one another (with the exception of hydrological fluctuations and other abiotic forces), therefore indicating strong patterns of sympatry (Knouft, 2003).

The need to integrate stream management and conservation of stream fishes stem directly from the recognition and awareness of patterns of microhabitat use, (Skyfield and Grossman, 2008), as many have become imperiled or even extirpated (Warren *et al.* 2000). This is particularly true of many darter species, as alterations of habitat from human development continue on such a large scale across the Midwest (Gammon, 1998; Lau, 2006). A large portion of Indiana's landscape is dominated by row crop agriculture, promoting channelization, eventually leading to increased erosion, sedimentation, and loss of riparian area, thus creating invariable microhabitat structure (Gammon, 1998).

Within Indiana, few studies have observed darter microhabitat usage and more specifically, between sites that differ in microhabitat availability and overall stream structure. This study ultimately identified patterns of darter habitat use while detailing individual life history needs that determine niche partitioning, migration, development, and behavior (Welsh and Perry, 1998).

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TABLE 1.—Location of sample sites, stream attributes, and most abundant species at each site. Drainage area estimated using Drainage Areas of Indiana Streams (Hoggatt, 1975). Two sites were sampled at both Killbuck Creek and White River. Primary substrates based on range (silt, sand, gravel, cobble, boulder, bedrock). Sites with an asterisk are located in the Upper White River watershed.

Name	Drainage area (km^2)	Avg. width (m)	Primary substrate (s)	Mean flow (m/s)	Mean depth (m)	Species
Bell Creek*	41.4	8.7	Cobble-boulder	0.11	0.16	Rainbow
Buck Creek*	233.1	19.2	Gravel-cobble	0.45	0.10	Rainbow
Bull Fork	38.1	10.1	Cobble-boulder	0.01	0.10	Orangethroat
Harvey Branch	23.1	7.1	Boulder-bedrock	0.04	0.08	Fantail/Orangethroat
Killbuck Creek(1)*	19.2	6.4	Silt-gravel	0.13	0.17	Johnny
Killbuck Creek(2)*	72.0	6.7	Silt-cobble	0.18	0.15	Greenside
Pipe Creek	41.0	8.3	Gravel-boulder	0.08	0.18	Rainbow
White River(1)*	572.4	18.3	Cobble-boulder	0.21	0.11	Greenside/Rainbow
White River(2)*	634.5	19.2	Cobble-boulder	0.21	0.07	Rainbow

TABLE 2.—Species distributions by stream/river collected for analysis. *N* is number of samples.

		Species				
Name	*N*	*E. blennioides*	*Ecaeruleum*	*E. flabellare*	*E. nigrum*	*E. spectabile*
Bell Creek	50	10	24	0	14	2
Buck Creek	18	7	11	0	0	0
Bull Fork	19	0	0	8	0	11
Harvey Branch	22	0	0	11	0	11
Killbuck Creek 1	31	14	0	0	17	0
Killbuck Creek 2	34	18	0	0	9	7
Pipe Creek	26	8	14	4	0	0
White River 1	38	19	19	0	0	0
White River 2	40	19	20	0	1	0
Total	278	95	88	23	41	31

TABLE 3.—Type and value of substrate based on the substrate category of the Qualitative Habitat Evaluation Index for each sampling location.

Site	Best types	Other types present	Silt	Embeddedness
Bell Creek	30% Boulder/70% Cobble	Detritus	Normal	Normal
Buck Creek	30% Gravel/70% Cobble	Silt, Artificial	Moderate	Moderate
Bull Fork	50% Boulder/50% Cobble	Detritus	Normal	Normal
Harvey Branch	40% Bedrock/60% Slab-Bld.	None	Free	Normal
Killbuck Creek(1)	10% Gravel/90% Sand	Silt	Normal	None
Killbuck Creek(2)	20% Sand/80% Cobble	Silt	Moderate	Normal
Pipe Creek	30% Boulder/70% Gravel	Detritus	Normal	Normal
White River(1)	50% Cobble/50% Boulder	Silt	Moderate	Moderate
White River(2)	20% Boulder/80% Cobble	Silt	Moderate	Extensive

FIGURE 2.— Principal Components Analysis ordination diagram (PC1 vs. PC2) of QHEI metrics between counties. Arrow indicates an increase in scoring of respective metrics. Axes labeled with most important contributing variables (component loadings of 0.3 or more).

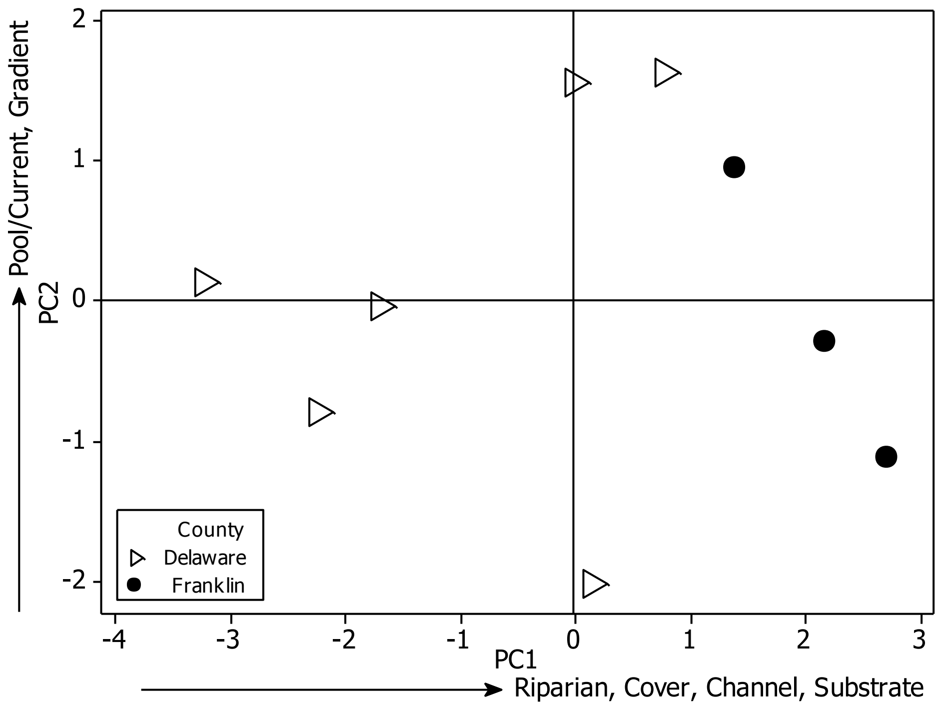


FIGURE 3.— Principal Components Analysis ordination diagram (PC1 vs. PC3) of QHEI metrics between counties. Arrow indicates an increase in scoring of respective metrics. Axes labeled with most important contributing variables (component loadings of 0.3 or more).

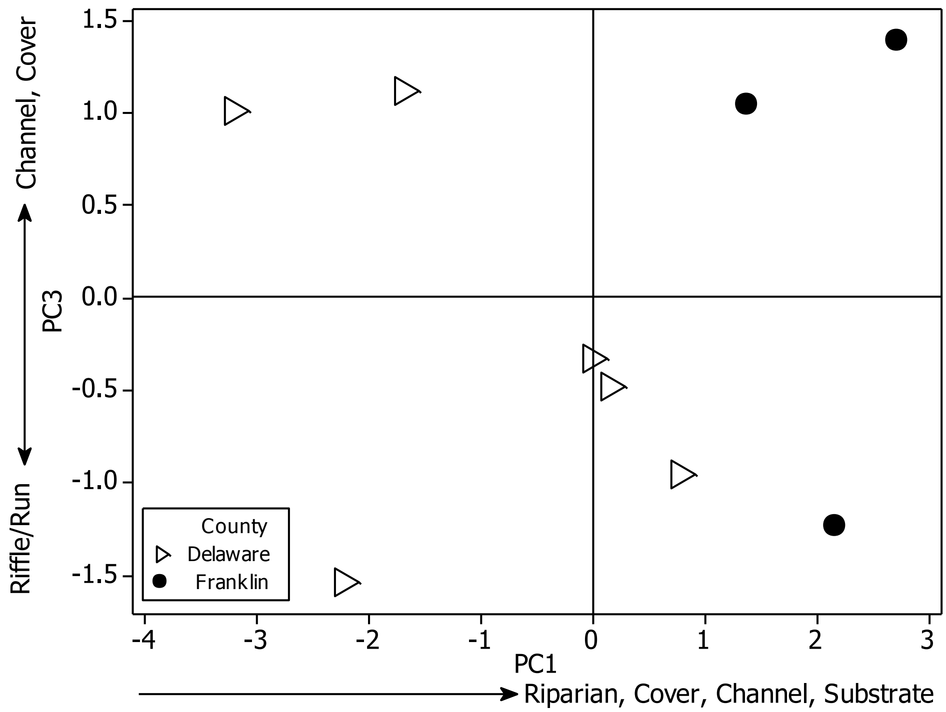


FIGURE 4.— Nonmetric Multidimensional scaling ordination diagram (NMS1 vs. NMS2) of microhabitat use of all darter species.

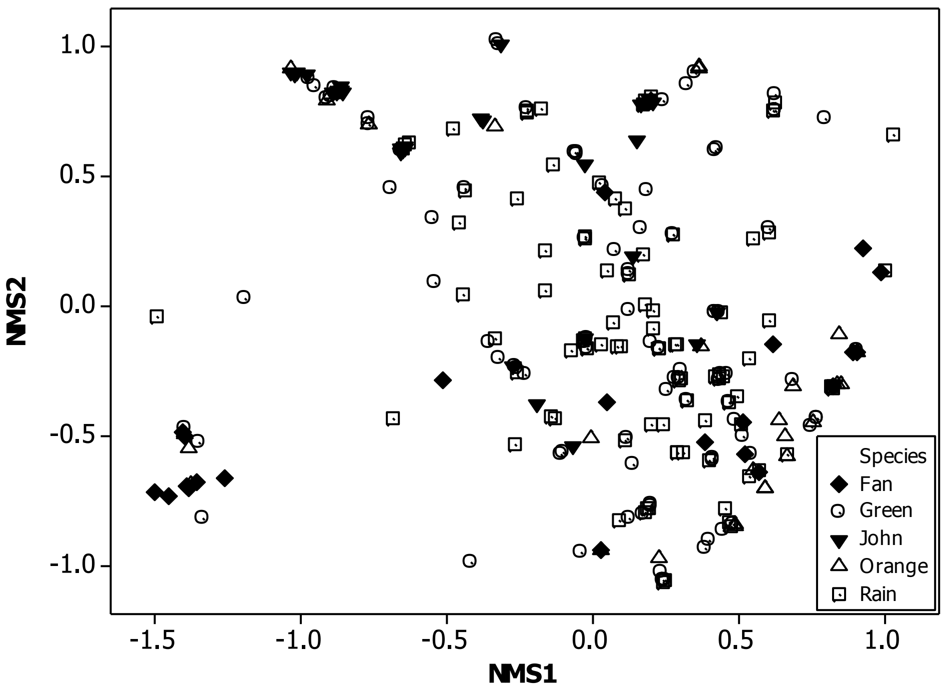


FIGURE 5.— Nonmetric multidimensional scaling ordination diagram (NMS1 vs. NMS3) of microhabitat use of all darter species.

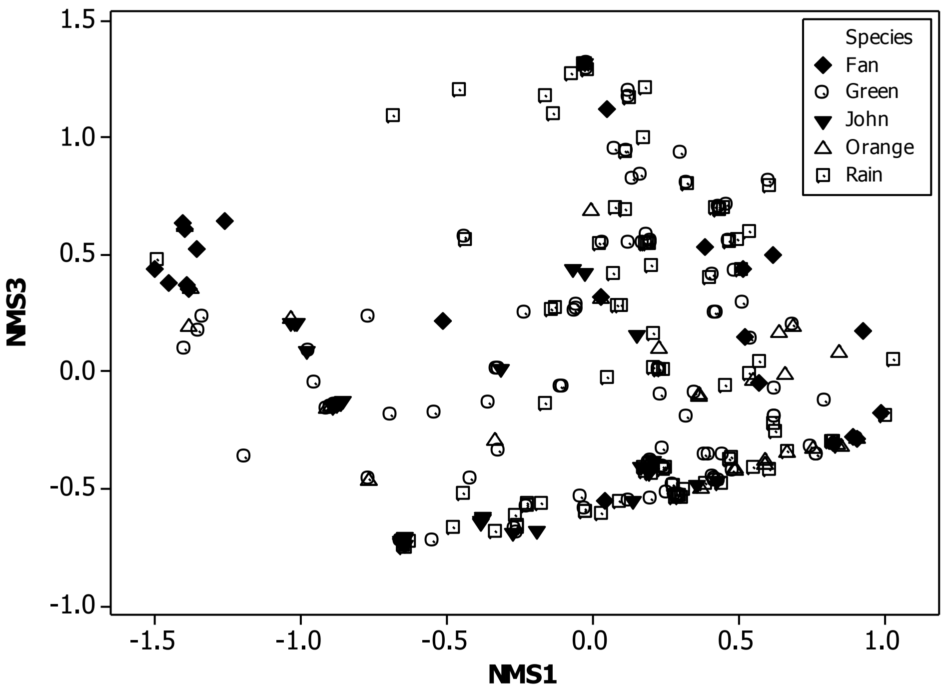
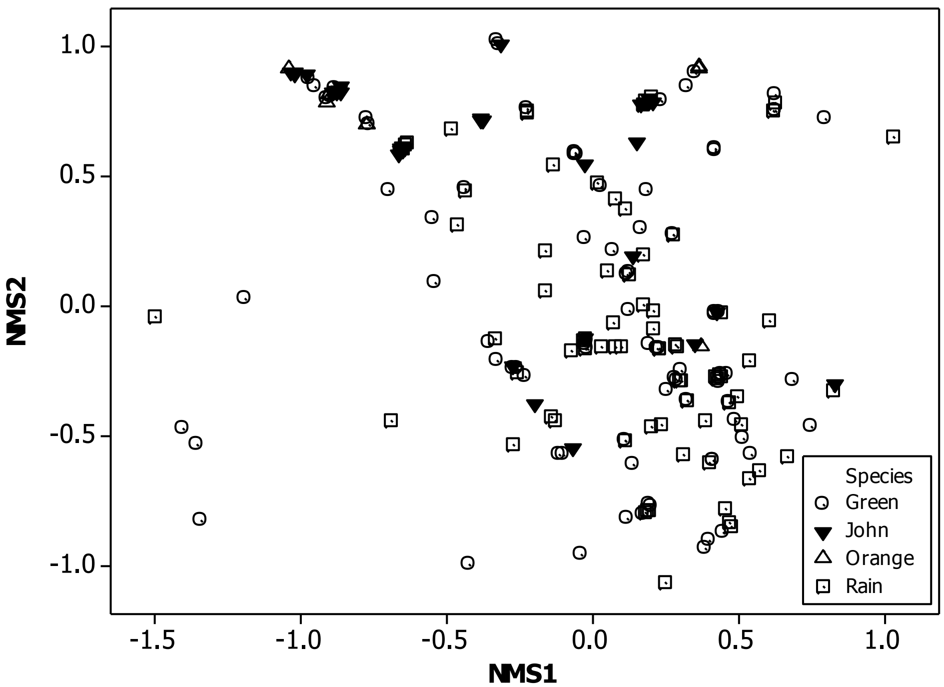
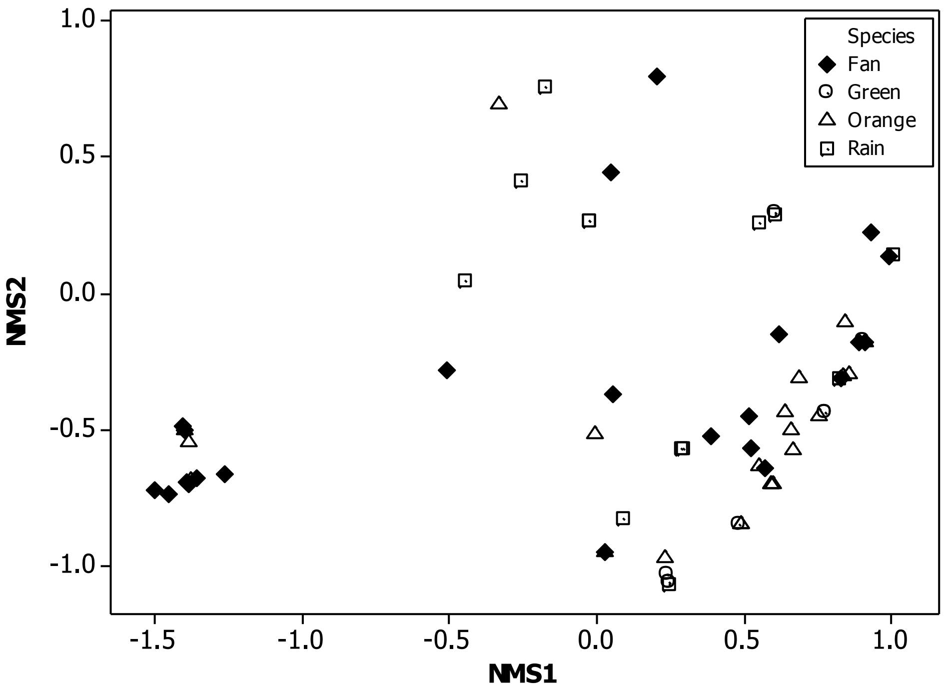


FIGURE 6.—Nonmetric multidimensional scaling ordination (NMS1 vs. NMS2) of microhabitat usage by species from the Upper White River watershed*.



*Note absence of fantail darter

FIGURE 7.—Nonmetric multidimensional scaling ordination (NMS1 vs. NMS2) of microhabitat usage by species from the Whitewater River watershed*.



*Note absence of johnny darter

FIGURE 8.—Nonmetric multidimensional scaling ordination (NMS1 vs. NMS2) of microhabitat usage data by species between watersheds (excluding fantail and johnny darters). County 1 is the Upper White River watershed and County 2 is the Whitewater River watershed.

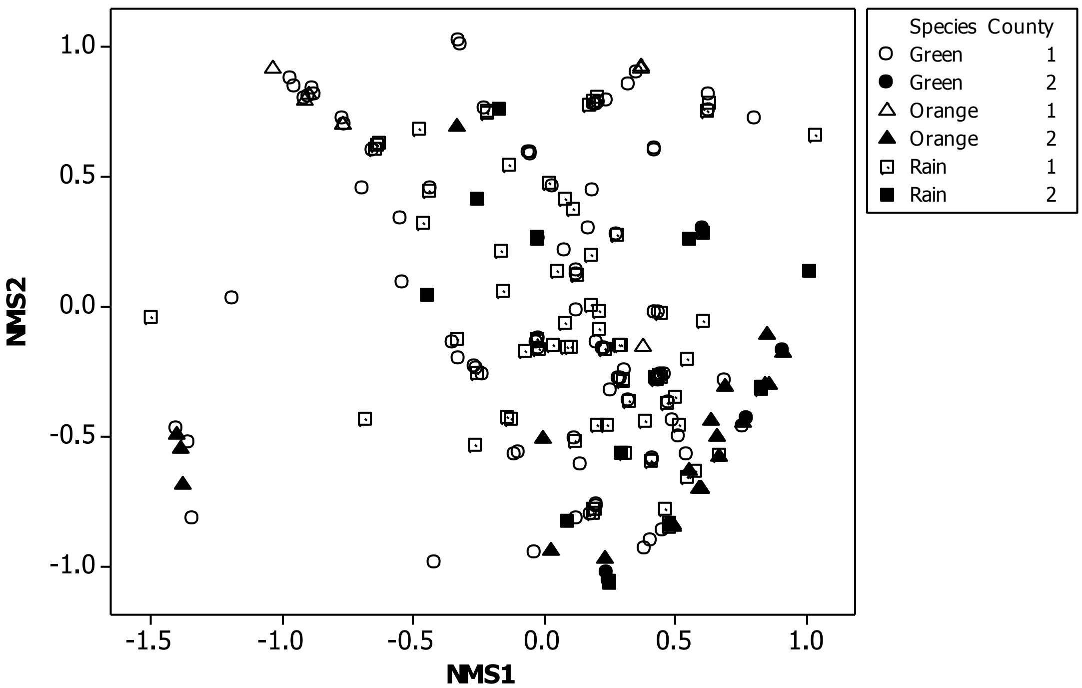
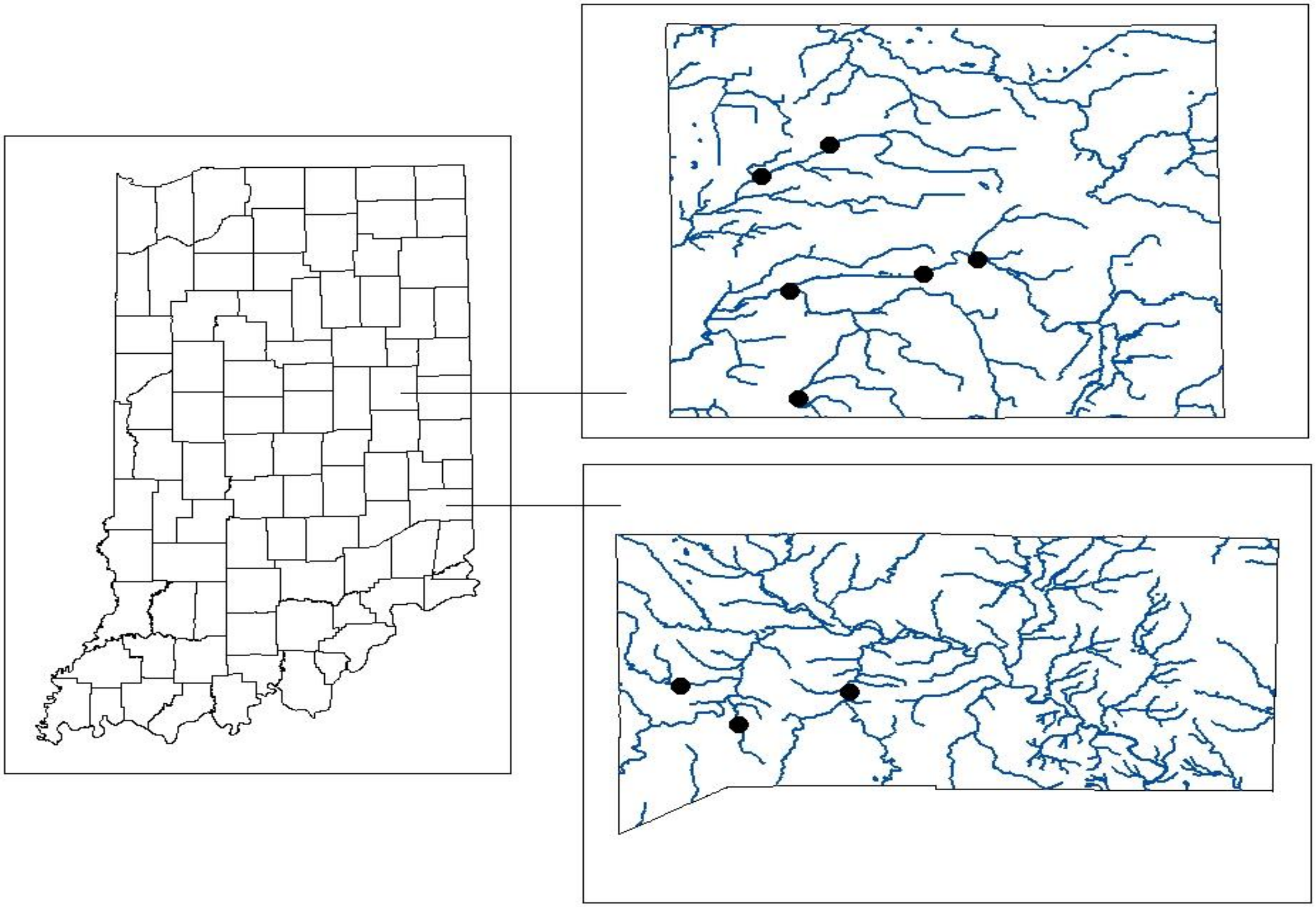


TABLE 5.—Results of multinomial logistic regression. Reference category is greenside darter. Slope indicates direction and strength of relationship. Alpha = 0.05.

	Microhabitat variables					
Species	Flow		Depth		Substrate	
	Slope	*P*-value	Slope	*P*-value	Slope	*P*-value
Fantail	3.1	<0.001	-4.6	0.002	0.02	0.022
Johnny	-1.6	0.018	*	*	-0.013	<0.001
Orangethroat	-3.9	<0.001	-5.2	<0.001	*	*
Rainbow	--1.0	0.003	*	*	*	*

* Denotes non-significant *P*-values and respective slope estimates

FIGURE 1.—Location of sampling sites. Top picture represents Delaware County, Indiana and bottom is Franklin County, Indiana.



Appendix 1. Stream site, location, and microhabitat information for each species.

Stream	Location	Species	Flow (m/s)	Depth (m)	% Bedrock	% Boulder	% Cobble	% Gravel	% Sand	% Silt
Bell Creek	400 W/700 S, Muncie	Rain	0.07	0.119	0	80	0	15	5	0
Bell Creek	400 W/700 S, Muncie	John	0.091	0.079	0	100	0	0	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.046	0.241	0	0	50	10	40	0
Bell Creek	400 W/700 S, Muncie	John	0.009	0.101	0	0	0	0	100	0
Bell Creek	400 W/700 S, Muncie	Rain	0.098	0.189	0	40	50	10	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.116	0.119	0	50	50	0	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.046	0.131	0	0	0	10	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.061	0.18	0	20	20	20	40	0
Bell Creek	400 W/700 S, Muncie	Green	0.03	0.271	0	20	0	0	80	0
Bell Creek	400 W/700 S, Muncie	Rain	0.137	0.259	0	50	0	0	50	0
Bell Creek	400 W/700 S, Muncie	Green	0.183	0.119	0	50	0	20	30	0
Bell Creek	400 W/700 S, Muncie	John	0.107	0.28	0	0	0	50	50	0
Bell Creek	400 W/700 S, Muncie	Green	0.015	0.189	0	0	0	20	80	0
Bell Creek	400 W/700 S, Muncie	John	0.003	0.11	0	0	0	50	50	0
Bell Creek	400 W/700 S, Muncie	Rain	0.006	0.189	0	0	0	50	50	0
Bell Creek	400 W/700 S, Muncie	Green	0.259	0.119	0	100	0	0	0	0
Bell Creek	400 W/700 S, Muncie	Green	0.305	0.101	0	80	20	0	0	0
Bell Creek	400 W/700 S, Muncie	Green	0.457	0.158	0	30	50	20	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.32	0.201	0	60	20	20	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.158	0.25	0	60	20	20	0	0
Bell Creek	400 W/700 S, Muncie	Green	0.183	0.149	0	0	0	50	50	0
Bell Creek	400 W/700 S, Muncie	Green	0.091	0.18	0	20	60	20	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.03	0.079	0	0	0	0	100	0
Bell Creek	400 W/700 S, Muncie	John	0.198	0.14	0	20	0	40	40	0
Bell Creek	400 W/700 S, Muncie	Rain	0.122	0.201	0	0	0	20	80	0
Bell Creek	400 W/700 S, Muncie	Rain	0.061	0.219	0	0	0	20	80	0
Bell Creek	400 W/700 S, Muncie	John	0.055	0.189	0	40	0	20	40	0
Bell Creek	400 W/700 S, Muncie	Rain	0.037	0.299	0	60	0	20	20	0
Bell Creek	400 W/700 S, Muncie	John	0.03	0.271	0	50	40	0	10	0
Bell Creek	400 W/700 S, Muncie	John	0.037	0.25	0	0	50	0	50	0
Bell Creek	400 W/700 S, Muncie	Rain	0.046	0.311	0	50	30	20	0	0

Bell Creek	400 W/700 S, Muncie	John	0.024	0.171	0	0	60	0	40	0
Bell Creek	400 W/700 S, Muncie	John	0.122	0.101	0	0	0	0	100	0
Bell Creek	400 W/700 S, Muncie	John	0.122	0.149	0	0	0	0	100	0
Bell Creek	400 W/700 S, Muncie	John	0.091	0.201	0	0	0	10	90	0
Bell Creek	400 W/700 S, Muncie	Green	0.122	0.229	0	0	50	20	30	0
Bell Creek	400 W/700 S, Muncie	John	0.107	0.229	0	0	50	50	0	0
Bell Creek	400 W/700 S, Muncie	John	0.213	0.03	0	0	0	50	50	0
Bell Creek	400 W/700 S, Muncie	Rain	0.183	0.091	0	40	30	10	20	0
Bell Creek	400 W/700 S, Muncie	Rain	0.219	0.101	0	20	30	25	25	0
Bell Creek	400 W/700 S, Muncie	Rain	0.003	0.061	0	0	0	50	50	0
Bell Creek	400 W/700 S, Muncie	Rain	0.003	0.061	0	90	0	0	10	0
Bell Creek	400 W/700 S, Muncie	Rain	0.067	0.079	0	50	50	0	0	0
Bell Creek	400 W/700 S, Muncie	Rain	0.003	0.07	0	0	0	0	100	0
Bell Creek	400 W/700 S, Muncie	Rain	0.213	0.049	0	0	0	80	20	0
Bell Creek	400 W/700 S, Muncie	Rain	0.015	0.061	0	0	0	80	20	0
Bell Creek	400 W/700 S, Muncie	Green	0.137	0.049	0	0	40	40	20	0
Bell Creek	400 W/700 S, Muncie	Orange	0.107	0.049	0	0	0	0	100	0
Bell Creek	400 W/700 S, Muncie	Rain	0.091	0.101	0	0	50	30	20	0
Bell Creek	400 W/700 S, Muncie	Rain	0.003	0.299	0	0	100	0	0	0
Buck Creek	Yorktown	Rain	0.427	0.046	0	0	90	10	0	0
Buck Creek	Yorktown	Rain	0.488	0.04	0	10	70	20	0	0
Buck Creek	Yorktown	Rain	0.61	0.101	0	10	60	20	0	0
Buck Creek	Yorktown	Green	0.671	0.101	0	0	10	10	0	0
Buck Creek	Yorktown	Rain	0.244	0.101	0	20	60	10	10	0
Buck Creek	Yorktown	Green	0.411	0.131	0	60	20	20	0	0
Buck Creek	Yorktown	Green	0.64	0.058	0	50	50	0	0	0
Buck Creek	Yorktown	Green	0.335	0.03	0	0	60	40	0	0
Buck Creek	Yorktown	Green	0.762	0.131	0	0	90	10	0	0
Buck Creek	Yorktown	Green	0.579	0.079	0	0	90	10	0	0
Buck Creek	Yorktown	Green	0.884	0.079	0	0	90	10	0	0
Buck Creek	Yorktown	Rain	0.396	0.201	0	40	40	0	20	0
Buck Creek	Yorktown	Rain	0.335	0.18	0	0	90	10	0	0
Buck Creek	Yorktown	Rain	0.183	0.04	0	50	50	0	0	0
Buck Creek	Yorktown	Rain	0.274	0.14	0	60	20	20	0	0
Buck Creek	Yorktown	Rain	0.305	0.14	0	15	15	10	60	0

Buck Creek	Yorktown	Rain	0.305	0.079	0	0	70	20	10	0
Buck Creek	Yorktown	Rain	0.183	0.149	0	0	0	5	95	0
Killbuck Creek 1	450 W, Muncie	John	0.158	0.201	0	0	0	10	90	0
Killbuck Creek 1	450 W, Muncie	John	0.152	0.28	0	0	0	10	90	0
Killbuck Creek 1	450 W, Muncie	John	0.061	0.122	0	0	25	25	25	25
Killbuck Creek 1	450 W, Muncie	Green	0.091	0.219	0	10	40	0	50	0
Killbuck Creek 1	450 W, Muncie	Green	0.152	0.201	0	0	10	0	90	0
Killbuck Creek 1	450 W, Muncie	John	0.177	0.201	0	0	50	30	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.122	0.101	0	0	60	20	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.152	0.122	0	20	30	0	50	0
Killbuck Creek 1	450 W, Muncie	John	0.152	0.299	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	John	0.122	0.079	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	Green	0.168	0.229	0	0	40	20	40	0
Killbuck Creek 1	450 W, Muncie	John	0.091	0.134	0	0	0	50	50	0
Killbuck Creek 1	450 W, Muncie	John	0.094	0.131	0	0	40	40	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.128	0.229	0	0	40	40	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.091	0.201	0	0	20	20	60	0
Killbuck Creek 1	450 W, Muncie	John	0.107	0.299	0	0	0	50	50	0
Killbuck Creek 1	450 W, Muncie	Green	0.107	0.201	0	0	60	20	20	0
Killbuck Creek 1	450 W, Muncie	John	0.091	0.131	0	0	0	0	50	50

Killbuck Creek 1	450 W, Muncie	John	0.183	0.11	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	John	0.152	0.201	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	Green	0.091	0.101	0	0	50	0	50	0
Killbuck Creek 1	450 W, Muncie	John	0.122	0.11	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	John	0.244	0.049	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	Green	0.122	0.131	0	50	0	0	50	0
Killbuck Creek 1	450 W, Muncie	John	0.183	0.201	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	John	0.091	0.049	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	John	0.061	0.079	0	0	0	0	100	0
Killbuck Creek 1	450 W, Muncie	Green	0.168	0.101	0	50	0	30	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.061	0.219	0	20	60	0	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.091	0.152	0	20	60	0	20	0
Killbuck Creek 1	450 W, Muncie	Green	0.107	0.299	0	0	50	0	50	0
Killbuck Creek 2	500 N, Gaston	John	0.055	0.131	0	0	0	0	20	80
Killbuck Creek 2	500 N, Gaston	John	0.027	0.171	0	0	0	0	30	70
Killbuck Creek 2	500 N, Gaston	Orange	0.03	0.049	0	0	0	0	20	80
Killbuck Creek 2	500 N, Gaston	John	0.152	0.21	0	0	0	0	20	80
Killbuck Creek 2	500 N, Gaston	Green	0.155	0.201	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	John	0.131	0.271	0	0	0	0	50	50
Killbuck Creek	500 N, Gaston	John	0.177	0.28	0	0	0	0	50	50

2										
Killbuck Creek 2	500 N, Gaston	Green	0.076	0.299	0	0	0	20	30	50
Killbuck Creek 2	500 N, Gaston	John	0.198	0.189	0	0	0	20	30	50
Killbuck Creek 2	500 N, Gaston	John	0.146	0.201	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	Green	0.158	0.25	0	0	0	20	30	50
Killbuck Creek 2	500 N, Gaston	Green	0.131	0.049	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	John	0.14	0.158	0	0	0	0	20	80
Killbuck Creek 2	500 N, Gaston	Green	0.094	0.299	0	0	0	0	30	70
Killbuck Creek 2	500 N, Gaston	Green	0.116	0.32	0	10	0	0	40	50
Killbuck Creek 2	500 N, Gaston	John	0.091	0.299	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	Green	0.183	0.183	0	0	40	40	20	0
Killbuck Creek 2	500 N, Gaston	Green	0.219	0.201	0	0	0	80	10	10
Killbuck Creek 2	500 N, Gaston	Green	0.009	0.201	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	Green	0.442	0.03	0	0	0	50	50	0
Killbuck Creek 2	500 N, Gaston	Green	0.213	0.122	0	0	0	50	50	0
Killbuck Creek 2	500 N, Gaston	Green	0.366	0.04	0	0	0	80	20	0
Killbuck Creek 2	500 N, Gaston	Green	0.158	0.101	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	Orange	0.076	0.101	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	Orange	0.198	0.049	0	0	0	0	50	50
Killbuck Creek 2	500 N, Gaston	Green	0.189	0.061	0	0	0	60	30	10

Killbuck Creek 2	500 N, Gaston	Green	0.198	0.03	0	0	0	50	50	0
Killbuck Creek 2	500 N, Gaston	Orange	0.107	0.061	0	0	0	0	80	20
Killbuck Creek 2	500 N, Gaston	Green	0.122	0.131	0	10	20	0	50	20
Killbuck Creek 2	500 N, Gaston	Orange	0.107	0.061	0	0	0	0	80	20
Killbuck Creek 2	500 N, Gaston	Green	0.091	0.122	0	0	0	0	80	20
Killbuck Creek 2	500 N, Gaston	Orange	0.107	0.04	0	0	0	60	20	20
Killbuck Creek 2	500 N, Gaston	Orange	0.152	0.04	0	0	0	60	20	20
Killbuck Creek 2	500 N, Gaston	Green	0.183	0.152	0	0	0	60	20	20
White River 1	McCulloch Park, Muncie	Green	0.457	0.131	90	0	0	0	10	0
White River 1	McCulloch Park, Muncie	Green	0.213	0.158	90	0	0	5	5	0
White River 1	McCulloch Park, Muncie	Green	0.762	0.329	100	0	0	0	0	0
White River 1	McCulloch Park, Muncie	Rain	0.03	0.201	0	90	0	10	0	0
White River 1	McCulloch Park, Muncie	Rain	0.03	0.07	0	40	0	10	0	50
White River 1	McCulloch Park, Muncie	Rain	0.091	0.101	0	10	0	0	0	0
White River 1	McCulloch Park, Muncie	Green	0.046	0.201	0	0	50	0	0	50
White River 1	McCulloch Park, Muncie	Green	0.03	0.03	0	80	0	10	0	10
White River 1	McCulloch Park, Muncie	Green	0.122	0.101	0	80	0	10	0	10
White River 1	McCulloch Park, Muncie	Rain	0.122	0.101	0	80	0	10	0	10
White River 1	McCulloch Park, Muncie	Green	0.015	0.101	50	0	0	0	50	0
White River 1	McCulloch Park,	Green	0.366	0.122	0	50	50	0	0	0

	Muncie									
White River 1	McCulloch Park, Muncie	Rain	0.396	0.091	0	80	20	0	0	0
White River 1	McCulloch Park, Muncie	Rain	0.046	0.122	0	50	0	0	0	50
White River 1	McCulloch Park, Muncie	Green	0.183	0.335	0	20	40	40	0	0
White River 1	McCulloch Park, Muncie	Green	0.03	0.122	0	50	50	0	0	0
White River 1	McCulloch Park, Muncie	Green	0.457	0.122	0	100	0	0	0	0
White River 1	McCulloch Park, Muncie	Rain	0.457	0.122	0	100	0	0	0	0
White River 1	McCulloch Park, Muncie	Green	0.183	0.061	0	70	30	0	0	0
White River 1	McCulloch Park, Muncie	Green	0.457	0.04	0	60	20	20	0	0
White River 1	McCulloch Park, Muncie	Rain	0.091	0.061	0	0	60	0	20	20
White River 1	McCulloch Park, Muncie	Rain	0.152	0.149	50	50	0	0	0	0
White River 1	McCulloch Park, Muncie	Rain	0.427	0.049	0	60	0	20	20	0
White River 1	McCulloch Park, Muncie	Rain	0.213	0.049	0	50	30	20	0	0
White River 1	McCulloch Park, Muncie	Green	0.213	0.049	0	50	30	20	0	0
White River 1	McCulloch Park, Muncie	Rain	0.03	0.03	50	0	0	0	0	50
White River 1	McCulloch Park, Muncie	Rain	0.366	0.079	0	60	20	20	0	0
White River 1	McCulloch Park, Muncie	Rain	0.335	0.119	0	0	70	30	0	0
White River 1	McCulloch Park, Muncie	Green	0.198	0.079	0	60	20	20	0	0
White River 1	McCulloch Park, Muncie	Green	0.152	0.03	0	100	0	0	0	0
White River 1	McCulloch Park, Muncie	Rain	0.091	0.061	0	100	0	0	0	0

White River 1	McCulloch Park, Muncie	Green	0.152	0.079	0	70	20	10	0	0
White River 1	McCulloch Park, Muncie	Rain	0.152	0.079	0	70	20	10	0	0
White River 1	McCulloch Park, Muncie	Green	0.457	0.061	0	80	10	10	0	0
White River 1	McCulloch Park, Muncie	Rain	0.152	0.119	0	100	0	0	0	0
White River 1	McCulloch Park, Muncie	Rain	0.213	0.061	0	10	80	10	0	0
White River 1	McCulloch Park, Muncie	Rain	0.107	0.305	0	50	0	20	30	0
White River 1	McCulloch Park, Muncie	Green	0.107	0.213	0	70	0	20	10	0
White River 2	Westside Park, Muncie	Rain	0.122	0.119	0	50	20	10	20	0
White River 2	Westside Park, Muncie	Rain	0.03	0.119	0	40	30	10	20	0
White River 2	Westside Park, Muncie	Rain	0.046	0.149	0	0	50	25	25	0
White River 2	Westside Park, Muncie	Rain	0.076	0.101	0	0	50	25	25	0
White River 2	Westside Park, Muncie	Rain	0.091	0.061	0	50	40	5	5	0
White River 2	Westside Park, Muncie	Rain	0.091	0.04	0	0	40	40	20	0
White River 2	Westside Park, Muncie	Rain	0.189	0.07	0	0	80	10	10	0
White River 2	Westside Park, Muncie	Rain	0.226	0.049	0	0	50	50	0	0
White River 2	Westside Park, Muncie	Rain	0.183	0.049	0	0	20	40	40	0
White River 2	Westside Park, Muncie	Green	0.177	0.061	0	0	20	40	40	0
White River 2	Westside Park, Muncie	Green	0.366	0.04	0	0	0	80	20	0
White River 2	Westside Park, Muncie	Green	0.29	0.049	0	0	0	90	10	0
White River 2	Westside Park,	Green	0.29	0.079	0	20	0	60	20	0

	Muncie									
White River 2	Westside Park, Muncie	Green	0.305	0.091	0	20	0	60	20	0
White River 2	Westside Park, Muncie	Rain	0.28	0.079	0	30	30	20	20	0
White River 2	Westside Park, Muncie	Green	0.274	0.049	0	80	0	10	10	0
White River 2	Westside Park, Muncie	John	0.107	0.07	0	0	0	10	90	0
White River 2	Westside Park, Muncie	Green	0.03	0.07	0	0	0	0	40	60
White River 2	Westside Park, Muncie	Rain	0.128	0.07	0	0	60	20	20	0
White River 2	Westside Park, Muncie	Rain	0.04	0.049	0	40	40	20	0	0
White River 2	Westside Park, Muncie	Green	0.29	0.101	0	40	40	20	0	0
White River 2	Westside Park, Muncie	Green	0.152	0.049	0	20	40	20	20	0
White River 2	Westside Park, Muncie	Rain	0.122	0.03	0	20	40	20	20	0
White River 2	Westside Park, Muncie	Rain	0.091	0.04	0	0	60	20	20	0
White River 2	Westside Park, Muncie	Green	0.171	0.101	0	40	30	0	30	0
White River 2	Westside Park, Muncie	Rain	0.107	0.049	0	0	40	50	10	0
White River 2	Westside Park, Muncie	Green	0.299	0.07	0	30	0	20	50	0
White River 2	Westside Park, Muncie	Green	0.259	0.07	0	30	0	20	50	0
White River 2	Westside Park, Muncie	Rain	0.274	0.079	0	0	50	0	50	0
White River 2	Westside Park, Muncie	Green	0.381	0.07	0	50	50	0	0	0
White River 2	Westside Park, Muncie	Rain	0.402	0.061	0	50	20	30	0	0
White River 2	Westside Park, Muncie	Green	0.411	0.061	0	30	0	20	50	0

White River 2	Westside Park, Muncie	Green	0.457	0.061	0	0	60	20	20	0
White River 2	Westside Park, Muncie	Green	0.183	0.07	0	0	0	0	100	0
White River 2	Westside Park, Muncie	Rain	0.259	0.07	0	0	40	0	60	0
White River 2	Westside Park, Muncie	Rain	0.305	0.049	0	40	40	0	20	0
White River 2	Westside Park, Muncie	Green	0.152	0.03	0	20	40	20	20	0
White River 2	Westside Park, Muncie	Rain	0.152	0.03	0	20	40	20	20	0
White River 2	Westside Park, Muncie	Green	0.274	0.07	0	0	80	15	5	0
White River 2	Westside Park, Muncie	Green	0.244	0.061	0	40	50	10	0	0
Bull Fork	Clarksburg	Fan	0.061	0.101	20	30	20	0	30	0
Bull Fork	Clarksburg	Orange	0.03	0.049	0	0	50	50	0	0
Bull Fork	Clarksburg	Fan	0.091	0.049	0	0	40	60	0	0
Bull Fork	Clarksburg	Fan	0.03	0.076	0	40	40	20	0	0
Bull Fork	Clarksburg	Orange	0.091	0.101	0	20	80	0	0	0
Bull Fork	Clarksburg	Orange	0.061	0.101	0	0	80	20	0	0
Bull Fork	Clarksburg	Orange	0.03	0.11	0	10	60	30	0	0
Bull Fork	Clarksburg	Orange	0.091	0.076	0	0	90	10	0	0
Bull Fork	Clarksburg	Orange	0.122	0.101	0	20	40	40	0	0
Bull Fork	Clarksburg	Orange	0.213	0.049	0	0	60	40	0	0
Bull Fork	Clarksburg	Fan	0.213	0.101	0	50	40	10	0	0
Bull Fork	Clarksburg	Orange	0.152	0.079	0	10	70	20	0	0
Bull Fork	Clarksburg	Orange	0.274	0.101	0	0	70	30	0	0
Bull Fork	Clarksburg	Orange	0.091	0.119	0	0	50	50	0	0
Bull Fork	Clarksburg	Orange	0.03	0.125	0	20	50	30	0	0
Bull Fork	Clarksburg	Fan	0.244	0.101	0	40	20	40	0	0
Bull Fork	Clarksburg	Fan	0.305	0.18	0	20	60	20	0	0
Bull Fork	Clarksburg	Fan	0.152	0.131	0	0	40	60	0	0
Bull Fork	Clarksburg	Fan	0.091	0.079	0	90	10	0	0	0
Harvey Branch	Oldenburg	Fan	0.03	0.101	95	5	0	0	0	0

Harvey Branch	Oldenburg	Orange	0.03	0.024	10	30	60	0	0	0
Harvey Branch	Oldenburg	Fan	0.03	0.024	10	30	60	0	0	0
Harvey Branch	Oldenburg	Fan	0.03	0.11	90	10	0	0	0	0
Harvey Branch	Oldenburg	Fan	0.015	0.101	0	10	70	20	0	0
Harvey Branch	Oldenburg	Orange	0.015	0.119	95	0	0	5	0	0
Harvey Branch	Oldenburg	Fan	0.015	0.119	95	0	0	5	0	0
Harvey Branch	Oldenburg	Fan	0.015	0.101	95	0	0	5	0	0
Harvey Branch	Oldenburg	Fan	0.03	0.04	95	0	0	5	0	0
Harvey Branch	Oldenburg	Orange	0.015	0.07	90	0	0	5	5	0
Harvey Branch	Oldenburg	Fan	0.091	0.03	0	0	0	50	50	0
Harvey Branch	Oldenburg	Fan	0.03	0.03	100	0	0	0	0	0
Harvey Branch	Oldenburg	Fan	0.061	0.009	100	0	0	0	0	0
Harvey Branch	Oldenburg	Fan	0.076	0.021	100	0	0	0	0	0
Harvey Branch	Oldenburg	Orange	0.03	0.131	100	0	0	0	0	0
Harvey Branch	Oldenburg	Orange	0.03	0.079	0	0	90	10	0	0
Harvey Branch	Oldenburg	Orange	0.03	0.149	0	10	0	10	80	0
Harvey Branch	Oldenburg	Orange	0.03	0.25	0	65	30	0	5	0
Harvey Branch	Oldenburg	Orange	0.061	0.101	0	10	30	60	0	0
Harvey Branch	Oldenburg	Orange	0.091	0.049	0	0	40	60	0	0
Harvey	Oldenburg	Orange	0.137	0.049	0	0	80	20	0	0

Branch										
Harvey Branch	Oldenburg	Orange	0.061	0.101	0	0	80	20	0	0
Pipe Creek	Metamora	Rain	0.03	0.131	0	5	25	0	70	0
Pipe Creek	Metamora	Rain	0.046	0.14	0	0	20	60	20	0
Pipe Creek	Metamora	Rain	0.04	0.21	0	0	90	0	10	0
Pipe Creek	Metamora	Rain	0.046	0.18	0	0	80	10	10	0
Pipe Creek	Metamora	Rain	0.058	0.21	0	0	80	10	10	0
Pipe Creek	Metamora	Rain	0.046	0.21	0	0	20	20	60	0
Pipe Creek	Metamora	Rain	0.03	0.21	0	0	20	20	60	0
Pipe Creek	Metamora	Rain	0.03	0.119	0	0	0	10	40	0
Pipe Creek	Metamora	Fan	0.061	0.149	0	0	10	30	60	0
Pipe Creek	Metamora	Green	0.122	0.11	0	50	0	50	0	0
Pipe Creek	Metamora	Rain	0.259	0.11	0	50	0	50	0	0
Pipe Creek	Metamora	Rain	0.015	0.201	0	0	10	10	80	0
Pipe Creek	Metamora	Rain	0.091	0.11	0	0	20	80	0	0
Pipe Creek	Metamora	Fan	0.229	0.119	0	0	20	80	0	0
Pipe Creek	Metamora	Rain	0.183	0.131	0	0	50	50	0	0
Pipe Creek	Metamora	Rain	0.229	0.131	0	0	50	50	0	0
Pipe Creek	Metamora	Fan	0.152	0.119	0	0	50	50	0	0
Pipe Creek	Metamora	Green	0.046	0.119	0	0	40	60	0	0
Pipe Creek	Metamora	Green	0.03	0.131	0	0	60	40	0	0
Pipe Creek	Metamora	Green	0.03	0.18	0	0	60	40	0	0
Pipe Creek	Metamora	Green	0.03	0.18	0	0	90	10	0	0
Pipe Creek	Metamora	Green	0.076	0.131	0	0	100	0	0	0
Pipe Creek	Metamora	Fan	0.061	0.11	0	10	10	80	0	0
Pipe Creek	Metamora	Green	0.076	0.149	0	0	100	0	0	0
Pipe Creek	Metamora	Green	0.03	0.119	0	10	90	0	0	0
Pipe Creek	Metamora	Rain	0.03	0.119	0	0	100	0	0	0

Appendix 2. Qualitative Habitat Evaluation Index (QHEI) scores and respective metric scores for each stream.

Stream	Substrate	Cover	Channel	Riparian	Pool/Current	Riffle/Run	Gradient	Score
Bell Creek	17	13	12	8	5	6	6	67
Buck Creek	15	8	7	4	8	6	6	54
Bull Fork	20	13	14	8	11	6	6	78
Harvey Branch	18	20	20	7	9	5	6	85
Killbuck Creek(1)	13	10	8	5	7	1	7	51
Killbuck Creek(2)	15	14	10	4	7	3	7	60
Pipe Creek	19	15	17	6	9	4	8	78
White River(1)	18	13	8	8	11	5	8	71
White River(2)	18	14	8	5	10	5	8	68