

IMPACT OF HYDROLOGIC CONNECTIVITY ON  
MACROINVERTEBRATE BIODIVERSITY IN THE  
SHIAWASSEE NATIONAL WILDLIFE REFUGE

By

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## ABSTRACT

Recovering obstructed hydrologic connectivity can be an important goal of restoration work in wetland ecosystems. Diked floodplain units, even when intensively managed, are often variably disconnected from adjacent river systems and thus present an interesting opportunity for studying the impacts of variations in hydrologic connectivity on floodplain communities. Both diked and naturally connected floodplains exist in the Shiawassee National Wildlife Refuge. The goal of my study was to assess how diked unit location and configuration influence the structure of macroinvertebrate community richness.

Using nested samples from vegetated microhabitats within larger floodplain units, aquatic macroinvertebrate surveys were conducted in the spring and summer of 2016. Water quality measurements were collected in the field while hydrologic connectivity was determined from existing map and LIDAR data layers. Trophic diversity was also studied through stable isotope analysis of top predators, common odonates, in the systems. Results suggest dike height (a proxy for flooding frequency) and channel distance from the river were important in determining community structure and richness within the refuge. Significant reductions in the taxonomic richness of floodplain macroinvertebrate communities were seen with increasing height and channel distance; in the refuge, each additional 1-meter in dike height reduced floodplain richness on average by one genus. Flooding height also significantly reduced the crustacean and gastropod diversity, altering the food web as seen in the significantly variable carbon and nitrogen isotope values. Stable isotope data showed higher trophic diversity in strongly connected sites, supporting my findings with respect to community composition. These results will be beneficial in assessing the impacts of the refuge's recent and future hydrologic restoration projects, and in general, my findings support the refuge's goals of monitoring improvements in wetland function and diversity.

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# DIVERSITY AND HYDROLOGIC CONNECTIVITY

## Introduction

Wetlands are highly productive habitats representing little more than 6% of the Earth's surface, but providing humans with valuable ecosystem services (e.g. flood protection, water purification, water recharge, and wildlife habitat) totaling an estimated worth of \$6,579 billion per year (Costanza et al., 1997). Never-the-less, floodplain wetlands are among the most heavily altered ecosystems on the planet and are a frequent target of restoration and mitigation programs (Tockner and Stanford, 2002; Millenium Ecosystem Assessment, 2005; Junk et al., 2013).

One factor making restoration of these natural environments more difficult is the ever-increasing fragmentation of our landscapes caused by human expansion and patterns of land use (Erwin, 2009; Tockner et al., 2010; Correa Ayram et al., 2016). In wetland dominated landscapes, physical fragmentation via drainage, land fill, and dike construction is often extreme, causing a loss of wetland habitat, hydrologic connectivity, and threatening diversity at multiple scales (Zedler and Kercher, 2005). While scientists have long discussed the importance of connectivity in terrestrial landscapes, the importance of hydrologic connectivity in aquatic ecosystems has only recently been studied as an essential component to wetland functionality and persistence (e.g. Pringle, 2001; Bayley, 1995; Bracken and Croke, 2007; Bouvier et al., 2009; Besacier-Monbertrand et al., 2014; Kowalski et al., 2014).

Pringle (2001) defines hydrologic connectivity as “the movement of matter, energy, or organisms facilitated by water”. In aquatic systems, hydrologic connectivity can include longitudinal (downslope), lateral (floodplain), and vertical (groundwater) connectivity.

The idea of connectivity is particularly important to floodplain wetlands, which are created and predominantly maintained by lateral connectivity with riverine systems. These wetland habitats have become the focus of several studies of hydrologic connectivity, organismal dispersal, and biodiversity (e.g. Bayley, 1995; Bilton et al., 2001; Amoros and Bornette, 2002). Consider the flood-pulse theory which identified annual lateral flood pulses as the key connectivity feature resulting in high tropical floodplain productivity (Junk et al., 1989; Bayley, 1995). More generally, local riparian flooding mechanisms can be quite complex, having longitudinal, lateral and vertical (groundwater) components that lead to the typically high beta-diversities in natural floodplain communities (Baker et al., 2001; Baker and Wiley, 2009)

While flooding is obviously necessary to have and maintain floodplain wetland habitats, it is often at odds with the societal goal of flood prevention to protect property and enhance agricultural production (Graf 1999). Humans have long been altering the aquascape with dams, artificial drainage, and increased impervious surfaces from urbanization, all of which have been shown to have problematic impacts on both the biology and hydrology of aquatic ecosystems (e.g. Rosenburg et al., 1997, Graf, 1999; Pringle, 2003;). On the other hand, the impact of dikes and levees, man-made earthen structures along rivers, is less clear (Rogers et al., 1994; Herrick and Wolf, 2005; Poulton and Allert, 2012).

Dikes are used to manage water levels on floodplains and rivers and consequently reduce the lateral connectivity and flood-pulse frequency of floodplain habitats. In some cases, the management goal is to exclude water, but in other settings (frequently in refuge systems) dikes are used to retain water on otherwise drained floodplain units. Much of



the research on dikes has occurred along ocean coasts (Rogers et al., 1994; Portnoy, 1999), where the design paradigm of diked vs un-diked management emerged. Restoration efforts in large floodplains now frequently consider dikes as impediments to hydrologic connectivity and focuses on assessing their impact on wetland vegetation and wildlife communities (e.g. Kowalski et al., 2014; Monfils et al., 2014). Floodplains with natural flood pulse frequencies provide refuge, spawning grounds, and foraging habitat for many aquatic organisms; thus, without natural flooding, the habitat that many organisms depend on is lost or greatly degraded (Bunn and Arthington, 2002).

In Michigan, only 2.6 million hectares of wetland remain of the once 4.3 million hectares of historic wetland, most of which is impacted by human manipulations to the hydrology (MDEQ, 2014). These lands are largely state and federally owned; with many of the wetlands managed using dikes (MDEQ, 2014). Researchers in the Great Lakes region have examined the impacts of dikes and hydrologic connectivity principally on coastal wetland vegetation (Kowalski et al., 2014), and economically important organisms like waterfowl and fish (Johnson et al., 1997; Bouvier et al., 2009; Kowalski et al., 2014; Monfils et al., 2014). Few studies have addressed macroinvertebrate community responses to hydrologic connectivity (Patrick et al., 2014).

The goal of this study was to assess the impact of hydrologic connectivity on macroinvertebrate community structure in connected and diked wetland units of the Shiawassee Flats. The Flats comprise an important complex of Great Lakes coastal wetlands that experiences differing levels of hydrologic connectivity to the Saginaw River tributary system as a part of a federally managed refuge (Shiawassee National Wildlife Refuge; SNWR). SNWR is currently the focus of substantial restoration efforts under the

Great Lakes Restoration Initiative (GLRI, 2014). The specific objectives of my study were to: 1) determine the extent to which hydrologic connectivity is important to macroinvertebrate community richness and wetland lower trophic food-webs; 2) examine how varying degrees of macroinvertebrate dispersal ability might mitigate the impacts of varied hydrologic connectivity (Hypothesis: Figure 11); 3) assess the impact connectivity has on trophic diversity in top predator taxa (odonates); and 4) develop novel and affordable methods of evaluating floodplain habitats and connectivity. Successful restoration in the Flats area will require knowledge about the ecological impact of the substantial system of isolating dikes and levees now in place and the potential implications of hydrologic re-connection.

## Methods

### Study Area

Research was conducted in the Shiawassee National Wildlife Refuge, a regionally important floodplain habitat of the Saginaw Bay watershed (Lake Huron) that is managed by U.S. Fish and Wildlife Services in a county (Saginaw) which has lost 87 percent of its pre-settlement wetlands (MDEQ, 2014). Established in 1953, SNWR was created to protect the habitat and increase waterfowl diversity and productivity in a 3,966-hectares floodplain complex known as the Shiawassee Flats. As with many federally owned floodplain and coastal refuges, the system is heavily diked, creating numerous large wetland pools with actively managed water levels (Figure 1). The refuge spans 40km<sup>2</sup> of the Shiawassee Flats, an inter-fluvial complex created by the convergence of 4 major tributary systems (the Cass, Flint, Shiawassee, and Titabawassee rivers). The habitats available to wildlife includes rivers, marshes, swamps, wet meadows, prairies, and upland

forests. My study focused on the managed marshes and floodplain units of SNWR. Water levels in most of these wetland units are highly regulated, using water control structures (gated and ungated), pumps, ditches, and dikes to manage the water levels. Floodplain habitats along the river channels and just outside of the diked units, however, are not managed and thus are subject to the stage fluctuations of the adjacent rivers.

Currently, the refuge is working on restoring hydrologic connectivity to one of the centrally located diked pools. This previously agricultural land is now reconnected with the Shiawassee River providing a study site for future expansion of this research to view the potential benefits of hydrologic restoration to macroinvertebrate communities.

### Study Sites

Study sites were located both on the refuge proper (n=16, Figure 1) at SNWR and nearby (upstream) at Brent Run near Montrose, MI (n=6, Figure 1) where a newly restored river channel and vernal pool complex provided additional opportunities to assess how macroinvertebrates colonize newly created isolated wetland habitats. My sites were placed into three categories based on their connectivity: *connected sites* (floodplains wetlands adjacent to a river), *diked sites* (floodplains behind a dike or levee), and effectively *isolated sites* (essentially vernal pools at the restoration site created by rain during the study period).

Sites at SNWR were selected to be as consistent as possible with earlier pre-restoration macroinvertebrate sampling (2013, Wiley personal communication) and the following criteria: I selected a series of sites around SNWR where (1) I could sample wetlands directly connected to the river channels during flood stage levels and (2) nearby

*unconnected sites* where the river was separated by dikes. Within these locations I tried to locate sites with (a) vegetation typical of marshes (cattails, rushes, reed grasses, submergent vegetation), and (b) no visibly flowing water (i.e., no current). Sites with standing water were sampled in May and July, which excluded some sites in the July sampling. Connected wetland units were all small enough to sample the entire wetland and all available microhabitats. Within the very large diked refuge units, I sampled multiple locations with varying distances from the river system and flooding heights but which still met the criteria for vegetation, presence of water, and lack of flow.

The microhabitats which were defined as localized habitats dominated and formed by a singular vegetation type. Thus, the sampling data were organized hierarchically by Type: (*connected, diked, or isolated*); management unit, i.e., site (e.g., Shiawassee, Pool 1A, Eaglemarsh, Grefe pool, etc.); and microhabitat defined by vegetation. Microhabitats were classified for each study site as open water, woody vegetation, emergent vegetation, or submergent vegetation with all studies sites having at least two microhabitats and many having three or four. At each site, the number of microhabitats were identified and random locations within the microhabitat were sampled. Area of each microhabitat was calculated using orthoquad imagery provided by refuge staff and used to create a weighted sum of richness for each site (Table 1).

Within each microhabitat and prior to macroinvertebrate sampling, vegetation cover and ancillary data were collected from two 1m<sup>2</sup> quadrats randomly selected using methods of Uzarski et al., (2004). Visual percent vegetation cover was estimated independently by two researchers and then averaged. Depth was measured at each site in the middle of each quadrat and averaged. Plant diversity was observed across each

microhabitat and coded as low, medium, high, or no vegetative richness as laid out in Table 2. During the summer sample period only, dissolved oxygen, total dissolved solids, and water temperature were collected using a YSI 556 Multiprobe system (YSI Inc.). Notes on site characteristics, time of day, and weather patterns were (including recent storms) also recorded as qualitative data for the site.

### Diversity Sampling

Sampling for macroinvertebrates at SNWR occurred over 3 weeks during both the spring and summer of 2016. Spring collections began May 9<sup>th</sup> and ended May 13<sup>th</sup>, with a total of 18 wetland units (sites) and 29 microhabitats visited. The Brent Run restoration site was also sampled during spring. Summer sampling (July 18<sup>th</sup> to the 29<sup>th</sup>) included 15 sites with 33 microhabitats (Figure 2). The larger number of microhabitats sampled during the summer were a result of greater vegetation growth and diversification in that season. The summer sample did not include the Brent Run sites and one SNWR site near the Flint River because they had dried out.

In total, 62 samples were collected at the microhabitat level, yielding 3,673 macroinvertebrates identified for the diversity analysis. The microhabitats were combined to create site-level variables. At each site and for both seasons physical and chemical variables were averaged and biological collections were pooled to get total richness values. This was done to avoid pseudo-replication because of the proximity of microhabitats within each site.

I developed a protocol for sampling diversity from the various wetland habitats modified from methods of Uzarski et al., (2004). Due to the large size and heterogeneity of the wetland sites, sampling smaller, representative microhabitats was necessary to

reasonably estimate site communities and characteristics. Before collecting macroinvertebrates, each site was assessed to determine the microhabitats present and for presence of standing water. Sampling for macroinvertebrates in each type of microhabitat present occurred within a 15-minute window; using a standard D-frame 0.5mm mesh dip net swept through the water column at all depths and across any vegetation. Time was added for sites where human mobility/efficiency was greatly reduced to assure consistent sampling effort. After the sampling, an additional 15 minutes were also used for picking out macroinvertebrates from sample trays. While sample efforts across the microhabitats were consistent the size and extent of microhabitats was not consistent. In order to avoid bias in the data collect, a weighted sum was calculated by adding up all the microhabitat samples collected in a site corrected by multiplying the percentage of area for each microhabitat.

All specimens, except species in the orders odonata and amphipoda, were placed in 70% ethanol for preservation and identification. odonates and amphipods were placed in vials and kept on dry ice while in the field to be cleaned and frozen for stable isotope analysis. To avoid bias during picking, researchers divided trays into 4 sections and sampled one section at a time removing all macroinvertebrates before proceeding to the next section. Identification occurred later in the lab using a dissecting microscope at 50x magnification. Most taxa in the class Insecta were identified to genus using Merritt et al. (2008), except chironomids which were identified to tribe. Amphipods were also identified to genus, while other non-insect orders found in low numbers were only identified down to family. Macroinvertebrate taxa were grouped by orders (e.g. beetles, dragonflies, flies, etc.) for analysis and comparison (Table 3).

### Classification of dispersal ability

Macroinvertebrates are key primary consumers in wetland food webs and can be a useful tool for managers to assess diversity and water quality status changes in altered hydrologic regimes (Goodnight, 1973; Whiles and Goldowitz, 2005; Vandewalle, et al., 2010; Buss et al., 2015). Pairing geospatial data with organisms' dispersal traits can be used to infer how organisms move across their landscape and survive (Ishiyama et al., 2014). Evidence to date suggests mobility-dependent responses can be assessed using trait databases for insects, which identify their varying capacities to disperse by air and water across complex landscape configurations (Brown and Swan, 2010; Ishiyama et al., 2014; Patrick et al., 2014).

The ability of taxa inhabiting each unit to disperse was also assessed. Taxa were classified into six categories as: *non-flyers*, *weak flyers*, or *strong flyers*; and as *non-swimmers*, *weak swimmers*, or *strong swimmers*. Non-flyers were classified as organisms which cannot disperse via the air (e.g. snails and mollusks), while weak and strong flyers were categorized using data from the trait matrix developed by Poff et al., (2006) and the trait database created by the U.S. Geologic Survey (Vieira et al., 2006). Swimming categories were classified using the same sources. Number/proportion of taxa at each site that fell into these six categories were totaled. *Strong swimmers* and *strong flyers* were combined to get total *strong dispersers*. This was also done for the *weak dispersers* and *non-dispersers* categories.

### Stable Isotope Analysis

Stable isotopes offer a quick method for assessing potential changes in carbon sources of a system and the nitrogen transfer between organisms (Thompson et al., 2005;

Gladyshev, 2009). Odonates were selected as the organism of interest because, as top predators in the system, they integrate a diversity of food sources. Amphipods were selected as an abundant and likely basal food source in the odonata food web. I expected that the combination of organism dispersal and lateral connectivity would have major impacts on what the diet of odonata predators would be; detectable by isotopic analysis.

The spring sampling period was used to collect odonates and amphipods from across the refuge with initial samples totaling 200 specimens. Dip nets were drawn across all vegetation and through the substrate in search of odonates and Amphipods. After rinsing off organisms they were stored in plastic vials in a cooler with dry ice during the fieldwork. Later, all specimens were placed in a freezer and stored until identification could occur. All specimens were identified down to genus for statistical analysis. After identifying a few highly productive sites for odonates, additional sampling efforts during the summer focused on six sites: three connected wetlands (Shiawassee 1, Shiawassee 2, and Eaglemarsh) and three diked pool units (Pool 1A, Pool 2A, and Flint; Figure 1). These sites were paired based on the similarity of units and stable isotope analysis was only conducted on samples collected at these sites.

Bulk carbon and nitrogen stable isotopes were extracted from individual organisms and pooled organisms (where minimum weight requirement was not met) of three odonata genera and collectively from amphipods (Table 10). The taxa were analyzed by family and included *Anax junius* (Common Green Darner; Aeschnidae), *Enallagma* spp. (Bluet Damselflies) and *Ischnura* spp. (Forktail Damselflies) pooled as family Coenagrionidae, and two families of amphipods that were combined; *Gammarus* spp. (Amphipoda: Gammaridae) and *Hyalella* spp. (Amphipoda: Hyalellidae). Samples were analyzed at Akron University Stable Isotope Lab in Akron, Ohio. Samples were combusted



and analyzed in a continuous flow isotope ratio mass spectrometer following standard procedures (Gladyshev, 2009). Atmospheric nitrogen was used as a standard to calculate the  $\delta^{15}\text{N}$  and pure carbon dioxide was used to calculate the  $\delta^{13}\text{C}$  values. Lipid extractions were conducted on 4 dragonflies and 6 damselflies to correct for lipids, which do not turnover like other tissues. Amphipods, which were initially collected as a primary consumer to calculate the trophic position of odonata species using equation 2 in Gladyshev (2009). Niche space and breadth were analyzed for the stable isotope data using the R package SIBER (RStudio Team, 2015).

#### Spatial Properties of the wetland units

Quantification of dispersal distance and spatial properties of sites was accomplished using ArcMap software (ArcGIS Version 10.4.1, ESRI Online). Analysis was conducted using 1m resolution orthoquad imagery obtained from USGS and topographic data collected by the US Fish and Wildlife Services. Connectivity variables calculated from the orthoquads at 1:2,400 scale included: area (diked and connected units, sample unit), *channel distance*, *flooding height*, average distance to nearby habitats, and straight-line distance from the site to nearest river (Table 3).

Area of diked units was estimated in ArcGIS (ArcGIS Version 10.4.1, ESRI Online) from aerial photograph using *dike* boundaries, while *connected* units were estimated using wetland upland vegetation divides and channels as boundaries. Area as well as volume was used in analysis depending on level of significance of the test. Volume was used as a potentially more accurate measure of aquatic habitat and was estimated by multiplying the unit area of water by the average sampled quadrat depth. Channel distance was calculated as the shortest distance an insect would need to swim from the

river's edge to each sample site. If a location was not directly connected to the river, then the distance was calculated using the location of the lowest obstruction, which would overflow first during a flooding event. Flooding height measured the average height of topological disconnect from the river to the wetland site. For unconnected sites, this was a dike created to manage the unit and for *connected* sites, this was the natural river banks. In some cases, the river was directly connected to the wetland without obstruction and so, the flooding height was recorded as zero. Flight distance was recorded as the shortest distance an insect could fly from the river's edge to all sites in a straight line, regardless of topography.

Dissolved oxygen in wetlands without currents is a function of fetch, wind velocities, temperature, and biologic activity (Bayley 1995). Working on this relationship, wetted fetch was calculated as relative aeration, when the oxygen concentration was not measured (spring sampling). The relationship between dissolved oxygen and wetted fetch was confirmed by regression analysis ( $p < 0.0001$ ,  $R^2 = 0.50$ ). All measurements for fetch were calculated based on the southwest prevailing winds that are most common in Saginaw, MI during the summer (National Climatic Data Center, [ncdc.noaa.gov](http://ncdc.noaa.gov)). Wetted fetch was calculated as open water without large shrubs in the unit at a 45-degree angle, southwest to northeast.

### Statistical Analysis

All data visualization and analysis were accomplished using RStudio (RStudio Team, 2015) and DataDesk (Data Desk 6, 2002). Taxonomic richness and Shannon diversity indices were calculated for the whole community and then by taxonomic and dispersal ability groups. Data collected in microhabitats were averaged for covariates and

pooled for richness to create a composite for each site. Data analysis was run at the site level unless otherwise mentioned. A correlation matrix was initially used to determine variables that were highly correlated (Table 4) and then Principle Component Analysis (PCA) was used to explore the importance of each variable to the sites (Figure 4 and 5). To assess the impact hydrologic connectivity had on macroinvertebrate richness and diversity linear regressions, general linear models (GLM), general linear mixed models (GLMM), and Analysis of Variance (ANOVA) were used depending on the type of variables and assumption requirements for statistical analysis. GLM analyses were run using the “glm” function in the “stats” package (Package *stats* version 3.3.2, RStudio). For the GLMM analyses, I used the “glmer” function in R package “lme4” (Package *lme4* version 1.1-12, RStudio). The hypothesis model was developed as a GLMM, with Richness metric (taxa counted per site) in sample  $i$ ,  $R_i$ , was analyzed with a Poisson likelihood function:

$$R_i \sim \text{Poisson}(\lambda_i)$$

And process model:

$$\ln(\lambda_i) = \alpha_{p(i)} + FH_{(i)} * \beta_1 + WF_{(i)} * \beta_2 + CD * \beta_3 + \ln(V)_{(i)} * \beta_4 + S_{(i)} \quad (1)$$

Where  $\alpha$  is the intercept for each plant diversity category  $P$ ,  $FH$  is the flooding height,  $WF$  is the wetted fetch,  $CD$  is channel distance,  $V$  is wetland volume (area x depth), and  $S$  is a random effect for season. This equation was also run with the dispersal categories as the dependent variable. All variables in the model were centered and standardized using R’s “scale” function due to the large differences between parameters and to make parameters comparable (RStudio Team, 2015).

## Results

### Differences related to Connectivity

Significant differences were seen in richness between *connected* sites and both *diked* and *isolated* sites (ANOVA,  $F = 52.39$ ,  $p < 0.0001$ , Table 3). The strongest difference was seen between *connected* sites and *isolated* sites (Figure 3a,  $p < 0.0001$ , difference = -22.75). The Shannon diversity indices calculated for each site were also significantly different showing the same pattern as richness (Figure 3b). Reductions in richness of floodplain macroinvertebrate communities were also seen with increasing *flooding height* and *channel distance*. Using equation 1 and coefficient values calculated in Table 6 it was found that each additional 1-meter increase in dike height reduced macroinvertebrate richness on average by one genus in the refuge.

Biological diversity (both taxonomic richness and Shannon-Weaver metric) was highest in the connected units and lowest in the un-connected recently colonized units at Brent Run (Table 3, Figure 3). A similar pattern was observed for many of the individual taxonomic groups. Significant differences between connected and unconnected sites were also observed for unit size (area), dissolved oxygen levels, and all three connectivity parameters. Dissolved oxygen was also statistically different when comparing the *diked* and *connected* floodplain sites. On the other hand, average plant cover, water temperature, and total dissolved solids were similar between types of sites.

Between the three site types there was variation in the community makeup and diversity. *Connected* sites had the highest richness and diversity, while the *isolated* wetland sites at Brent Run had the lowest; composed largely of first colonizers (Table 3). Analysis of variance confirmed the difference seen between site type and richness ( $F =$

52.31,  $p < 0.0001$ ) as well as Shannon diversity ( $F = 25.09$ ,  $p < 0.0001$ ). Besides differences in overall diversity, the sites also had noticeable differences in crustacean and gastropod diversity. The *diked* sites had lower diversity than *connected* sites and the *isolated* sites had Shannon diversity scores of zero in these two groups (Table 3). Diversity in other macroinvertebrate categories consistently found *connected* sites with the highest index scores. Generally, the *isolated* sites had lower diversity than the *diked* sites, except in the cases of Coleoptera, Diptera, and ET (Ephemeroptera and Trichoptera) diversity (Table 3). Multiple comparisons of site type showed significantly lower diversity in the *diked* and *isolated* sites when compared to the *connected* sites, but often there was no statistical difference between *isolated* and *diked* sites.

#### Effects of Vegetation

Analysis by vegetation type (emergent, submergent, woody, or open water) indicated that for most groups, richness did not have a strong relationship to degree or class of vegetation cover. Beetles seemed to prefer reeds over submergent vegetation ( $p = 0.4$ ) and Strong flyers were more often associated with emergent reeds rather than open water ( $p = 0.03$ ). Strong flyers were more common in habitats with more diverse vegetation ( $p = 0.04$ ). A principle component analysis of the environmental variables separated *connected* sites from the other categories based on size, relative aeration and percent vegetative cover (Figure 4, Table 5).

#### Components of connectivity

Two of the six connectivity variables, *channel distance* and *flooding height*, were significantly related to various aspect of macroinvertebrate assemblage diversity. *Channel distance* was significantly related to overall diversity at the microhabitat scale (Linear

Regression,  $F = 7.63$ ,  $p = 0.008$ ) explaining about ten percent of the overall variance ( $r^2 = 0.101$ ), but not at the site level ( $F = 0.64$ ,  $p = 0.43$ ). On the other hand, *flooding height* (related to frequency of connection) was significant at both scales (Microhabitat:  $F = 17.65$ ,  $p < 0.001$ ; Site:  $F = 11.65$ ,  $p = 0.002$ ) and explained more of the data at the site level ( $r = 0.26$ ). While correlation between the two measurements of hydrologic connectivity was significant (Pearson's Correlation:  $r = 0.52$ ,  $n = 31$ ,  $p < 0.0001$ ) both measurements are considered here because they clearly reflect different kinds of constraint on dispersal and were related differently to both biological and physical characteristics of the study sites. For example, the use of both metrics in the PCA models increased the variance explained by the first two components (Figure 5, Table 5).

### Statistical Modeling

Modeling at the site scale produced better fits than modeling at the microhabitat scale (Table 6). Flooding height and channel distance were both consistently significant in the site level GLM and GLMM analyses. Models using flooding height had lower AIC scores and higher  $R^2$  values than models using only channel distance as the explanatory variable, but the best-fit model included both parameters (Table 6). The best model to predict overall taxonomic richness included fixed variables for flooding height, relative aeration, channel distance, and log transformed volume with random effect variables for categorical plant diversity and season (AIC 217.7,  $R^2 = 0.85$ ; Figure 6). Among the other models I tested, flooding height was consistently important while vegetation type, relative aeration, and volume (area x depth) or simply area alone were also often important components improving the  $R^2$  values, but were not always statistically significant (Table 6). I also explored a nested model with vegetative samples nested in sites but it explained

significantly less variation, likely due to the lack of variability in microhabitats richness ( $R^2 = 0.24$ , Table 6).

### Connectivity and Dispersal Ability

Flooding height alone accounted for little of the variation in overall richness between categories of dispersal ability (Figure 7). Connectivity was substantially modified by dispersal ability for at least some groups of macroinvertebrates (Figure 3c, d, and e). Flightless groups like Crustaceans (Figure 3c) and Gastropods were only found in very low numbers at a few of the *isolated* sites and in low numbers in the *diked* sites (Table 3). Richness for these groups was zero for the least connected sites, while *connected* sites had twice the biodiversity as the *diked* sites. On the other hand, beetle richness, a group with strong flight ability, did not vary with site connectivity (Figure 3d). The odonates, another group with strong flight abilities, did show some variation in richness related to connectivity but without statistical significance (Figure 3e).

GLMM modeling stratified by dispersal category (*Strong*, *weak*, and *non-flyers/swimmers*) and using the same best fit approach as above (Equation 1) indicated *Non-flyers* were the group most highly impacted by flooding height ( $\beta_1 = -0.188$ ) (Table 8). Similarly, the *non-swimmer* group was more affected than either of the more dispersive groups, although the relationship was less than for the *non-flyer* group (Table 8). However, flooding height was not statistically significant in the GLMM model for either *weak flyers* or *swimmers* (Table 8). Separate analysis of the two dispersal abilities, flight and swimming, was not attempted because of the high correlation between the two (non-swimmers/non-flyers 0.85, weak dispersers = 0.80, and strong dispersers = 0.94). Using the combined dispersal categories in the GLMM model instead revealed a negative

trend with flooding height for *non-dispersers*, a positive trend for *strong dispersers*, and no trend with *weak dispersers* (Table 8).

### Connectivity and Food Web Dynamics

Delta nitrogen values for dragonflies and damselflies were higher in connected sites than in diked sites (Table 9; Paired Wilcox test:  $p < 0.0001$ ,  $V = 1175$   $n = 51$ ). A similar trend was also seen in the carbon values (Paired Wilcox test:  $p = 0.011$ ,  $V = 936$ ,  $n = 51$ ). Delta N values for damselflies, dragonflies, and amphipods in Eaglemarsh were higher and statistically distinct from values at the other sites for nitrogen isotope values (ANOVA: all groups  $p < 0.0001$ ,  $n = 52, 63, 27$ ). Delta carbon isotope values were highest at the Shiawassee 2 site and second highest in the diked Flint site (Figure 10). Carbon values were only statistically different between sites for the damselflies (ANOVA:  $p < 0.0001$ ,  $Z = 59.83$ ,  $n = 63$ ).

In the following comparison between isotopic values from the three taxa, I am omitting the Eagle Marsh –Flint site data because (1) the Eagle Marsh values suggest something unique is happening there in terms of N processing (possibly high rates of denitrification or organic contamination) and (2) no amphipods were collected at the Flint connected wetland site. Dragonfly (*Anax junius*), and damselfly (Family: Coenagrionidae) nitrogen values were not found to be significantly different, but both of those groups were statistically higher in delta N (heavy N) than amphipods (ANOVA:  $p = 0.0001$ ,  $Z = 9.762$ ,  $n = 124$ ). Interestingly, the amphipods were found to have higher carbon isotope values than both Odonata groups (ANOVA:  $p = 0.004$ ,  $Z = 5.66$ ,  $n = 124$ ) and again, the odonates were not significantly different from each other.



Stable isotope means (Table 9) and niche spaces were estimated for dragonflies and damselflies using SIBER summary statistics (Table 10). Dragonflies consistently had larger niche spaces within each site (Table 10). Shiawassee 1 had the largest niche spaces for dragonflies (11.8) and damselflies (6.6). The pairing of sites (Shiawassee 1 with Pool 2A and Shiawassee 2 with Pool 1A) shows that the trend of larger niche space was not consistently seen in connected sites because Pool 1A had much higher standard ellipse areas than Shiawassee 2 for dragonflies even when corrected for sample size (Table 9). Plotting the niche spaces shows that connected sites (Shiawassee 1 and 2) were higher in nitrogen 15 and often higher in carbon 13 than the diked sites (Figure 10). Means and standard deviations seen across sites showed significant differences in average values and variations between *connected* and *diked* sites (Table 10).

## Discussion

### Differences Related to Connectivity

The differing ways in which hydrologic connectivity has been conceptualized and defined in the literature has contributed to a lack of consistent methods for studying it (Junk et al., 1989; Pringle, 2001; Amoros and Bornette, 2002; Bracken and Croke, 2007). Many have measured connectivity in terms of binary or categorical metrics which limit quantitative interpretations (Paillex et al., 2013; Zilli and Paggi, 2013; Dou et al., 2016). Eros et al. (2012) used simple Euclidian distances to show the relationship of dispersal ability and community composition change for distant habitat patches, a method which has been taken up by researchers (i.e. Ishiyama et al., 2014 and Patrick et al., 2014). I have here combined distance parameters, dispersal ability of macroinvertebrate taxa, and categorical connectivity metrics to develop simple statistical models which demonstrate

the positive effects of connectivity on macroinvertebrate diversity, a method which could be easily applied in management settings.

The size of a wetland can impact the connectivity and by itself is also a factor affecting biodiversity. Island biogeography theory (MacArthur and Wilson, 1967) provides a general basis for expecting increasing diversity with wetland unit size. Improved statistical fits of models which included unit size presumably reflect this effect even though many of the large *diked* sites did not have higher diversity. Paillex et al. (2007) analyzed macroinvertebrate diversity across a varying hydrologic gradient finding a quadratic response to unit area with highest diversity occurring in intermediately sized units. I found no significant quadratic or exponential trends, however, but additional data from a wider size gradient might yield different results.

Conceptually, very large size diked units might limit immigration rates from adjacent rivers simply by the scale of area needed to be traversed. I believe this was likely the case in Pool 1A (Figure 1) in which the weighted richness for samples collected near Shiawasse River were much higher than the richness for samples collected on the south side and furthest portion from any river (Table 1). Wetlands, unlike islands, also have a depth component which factors into the persistence of the habitat, temperature, and dissolved oxygen all important to species survival and reproduction which will be discussed in the section on “The Role of Dispersal Ability”.

#### Other Factors Influencing Wetlands

Wetlands biodiversity is, of course, not only affected by hydrologic connectivity, but other environmental conditions important to the system (Hale et al., 2016). Hydroperiod, predator presence, habitat size and availability, and water quality

parameters have all been shown to have a strong impact on wetland function and biodiversity (Eloranta et al., 2015; Hale et al., 2016). Thus, it is important to control for other factors which might also influence macroinvertebrate diversity (Tockner et al., 2010). In my study, ancillary data was collected to account for other potential sources of variability. Measured variables included: conductivity, dissolved oxygen, and temperature. While only oxygen showed a significant trend with biodiversity here, complex environmental gradients can be intertwined and difficult to describe. Rooney and Bayley (2012) found a high concordance between environmental factors like oxygen concentrations, turbidity and biotic diversity. They also identified fish as a major driver of macroinvertebrate diversity in emergent wetlands (Rooney and Bayley, 2012). While I did not examine impacts of fishes, there are clearly reasons to expect covariance's between fish and macroinvertebrate diversity in Great Lakes coastal wetlands (Kowlaski et al., 2014)

Dissolved oxygen availability is a major constraint in all aquatic communities, and especially so in wetland habitats. Wetlands are typified by low oxygen levels that fluctuate greatly throughout the day and which many species cannot tolerate. The significantly different dissolved oxygen regimes I found between *connected* and *diked* sites explained some of the observed distribution pattern in organisms like mayflies (Ephemeroptera) which are relatively intolerant of low DO. Other water quality factors like nutrients, pH, organic carbon, and toxic pollutants can also impact primary and secondary production, which in turn drive community complexity. Impaired connectivity has been shown to limit, reduce, or impair many of these water quality components in wetland systems (Junk and Furch, 1991; Rachetti et al., 2011; Wolf et al., 2013; Covino, 2017).

## Effects of Vegetation

Vegetation is another factor often considered to be important in shaping floodplain wetland communities; so much so that wetlands are typically classified by their plant communities. Hydrologic connectivity can affect both what plants become established and how densely they grow (Bayley and Guimond, 2007; Pollock et al., 1998). The plant community in turn affects the macroinvertebrates, fish, and birds that utilize the wetland (Kowalski et al., 2014; Rooney and Bayley; 2012). For example, Kaller et al. (2015) found vegetation type to be an important explanatory variable for macroinvertebrate community assemblages across hydrologic gradients in wetlands. Vegetative diversity may also explain some of the variation seen between sites in this study, although I could not find a significant effect of vegetation types, diversities, or percent cover. However, my relatively simplistic characterization of vegetation into percent cover and successional stage did not include plant diversity, which may limit the understanding of vegetation's importance. On the other hand, macrophyte cover and density are often related to both macroinvertebrate and fish population density (e.g. Wiley et al. 1984), which is sufficient basis for the use of my vegetative metrics.

## Components of Connectivity

I initially defined connectivity more broadly than some, using several connectivity parameters which tried to capture differing aspects of the problem: *dike height*, *channel distance*, flight distance, several measures for nearby microhabitats, and distance from the Shiawassee River. The two statistically significant and interpretable measurements I found were *dike height* and *channel distance*. Dikes are engineered flow obstructions in

floodplains that have come under scrutiny as impediments to organism dispersal and hydrologic routing (Junk et al., 2013; Smith et al., 2008). Dike height, interpreted as a level of disconnection, showed a significant negative correlation with macroinvertebrate diversity in my study, a consistent result found by others using different methods (Tockner et al., 1999; Paillex et al., 2007; Paillex et al., 2013; Besacier-Monbertrand et al., 2014; Dou et al., 2014; Kowalski et al., 2014). For a given flow, path dike height will constrain flooding according to the exceedance frequency of the relevant stage-discharge relationship. High dike heights will result in low frequency flooding, whereas low heights will result in relatively high frequency flooding. Amoros and Bornette (2002) suggested in their review of connectivity literature that an intermediate frequency of temporal connectivity (i.e., flooding) increases aquatic biodiversity, including macroinvertebrates, while human alterations like dikes, levees, and dredging reduced biodiversity. My data, however, contained no suggestion of an intermediate optimal response to dike height. More detailed information about the actual frequency of flooding, and detailed flow routing within my study site would undoubtedly be useful in characterizing the exact nature of the links between flood frequency, dike height constraints, and macroinvertebrate diversity.

In addition to dike height as a constraint on flooding frequency, I also found a statistically significant effect of dispersal distance, which I studied using the parameter *channel distance*. Several studies have used estimates of dispersal distance to test how macroinvertebrate dispersal ability impacts biodiversity. Some have used the straight-line distances or flight distances, showing that only strong flyers can reach distant habitat patches which reduces the biodiversity at those sites (Galic et al. 2013; Ishiyama et al. 2014; Patrick et al., 2014). I examined several straight-line distance parameters from

various river sources to habitat patches, but no trend was identified. *Channel distance* from source habitats (the shortest distance in which water will flow from the river source to wetland sink habitats), however, was related to decreases in diversity in my study. Several others have used this approach which relies on channel flow patterns to determine where organisms can passively or actively disperse through water (Rogers et al., 1994; Roach et al., 2009; Vinegre et al., 2011).

*Channel distance* was an important variable in improving my regression models. It likely represents the added costs and risks of moving long distances between useable habitat patches. From a management perspective, *channel distance* is a useful measurement because refuge managers have control over the number and location of water flow structures installed. By controlling where water flows and how fast it flows, we likewise affect how easily organisms can move between habitat patches. *Channel distance* has been shown to impact fish and crustacean stock in managed marshes (Rogers et al., 1994) and fish in the Mississippi floodplains (Roach et al., 2009). One aspect of *channel distance* which was not measured in my study and could have an impact is water velocity in the channels. Water velocity could positively impact diversity by moving more organisms per unit time into the habitat or negatively by physically damaging organisms. Roach et al. (2009) found that flow rates could have an impact on food chain length in fish communities using stable isotope analysis. Consideration of flow patterns and speeds could explain some of the unexplained variation in community composition in my study and should be added to measurements taken in the future.

## The Role of Dispersal Ability

The analysis of distance parameters was taken up as a means of getting closer to understanding how hydrologic connectivity works. Instead of just using categories of connectivity, this study assessed the potential for dispersion through water by using *flooding height* as a proxy for frequency of flooding and *channel distance* as distance to new habitat patches for macroinvertebrate species. While the two parameters were highly correlated, they describe different processes inhibiting macroinvertebrate dispersal. The importance of both dike height and channel distance in my statistical models shows that both quantitatively impact the diversity in topographically complex wetland habitats.

From the theory of island biogeography (MacArthur and Wilson, 1967), ecologists have understood that immigration and emigration rates of taxa are related to the size of habitat patches and the distance between patches (MacArthur and Wilson, 1967; Gilpin and Hanski, 1991). In this study, *channel distance* represents the distance from permanently wet source areas (river habitats) and unit area represents sink (i.e., island) patch size. Increasing *channel distances* did reduce diversity but not to the magnitude I expected. The additional component of depth mentioned earlier may help explain this reduced magnitude. The volume of a wetland habitat, derived from depth and area, represents the total area available to aquatic organisms. Deeper waters and larger volumes provide persistent water year-round for macroinvertebrates. With a stable habitat that is not experiencing drying or anoxic condition, macroinvertebrates can persist for longer periods in a wetland and thus, receiving immigrants from the river is not as vital. In other words, in terms of the Island Biogeographic framework, local extinction rate likely declines with increasing wetland unit size.

Consideration of dispersal ability is important when habitat area and depth, both identified as important factors in this study, are similar. Due to the strong correlation between swimming ability and flight ability, only flight ability will be considered in this discussion. Consistently, the non-flyers were heavily impacted by connectivity, while variations between weak and strong disperser groups were weakly affected. Given an island biogeographic paradigm, we should expect patches far away from the river (large *Channel distance*) to have fewer non-flyers and weak flyers than strong flyers. This was not always the case and is likely due to the relatively small distance between sites (<1km).

*Flooding height* (i.e. flooding frequency) represents the opportunity for large scale immigration events from the river to the floodplain. *Flooding height* was positively related to *strong flyers* because the dike or levee represents a barrier to the floodplain which only high flight ability organisms can traverse. Flooding parameters were important in the statistical analyses, but the combination of *flooding height* and *channel distance* improved the models. Likely, there is an interaction between flooding events replenishing organisms and nearby patches experiencing higher overall immigration. Given the data I collected, I was unable to disentangle the interaction between *channel distance* and *flooding height*, largely due to the correlation between flight ability and swim ability. Future researchers should consider tracking individuals with specific, but different, flight and swimming abilities to determine how travel distance and flooding frequency interact to structure communities within wetland complexes.

In most studies of dispersal ability, as in my study, the strongest flying macroinvertebrates are found in the most distant habitats and are more similar throughout the study area (Bilton et al., 2001; Ishiyama et al., 2014; Patrick et al., 2014)



Obolewski et al., 2015). While the energetic cost of flight often reduces the abundance of flighted organisms compared to flightless organisms generally (Bilton et al. 2001), the lack of connectivity in my study site choose for only strong flyers (beetles, bugs, true flies, and dragonflies). The higher diversity found in midges at the restoration sites can be explained by the isolation and simplification of the floodplain pools, which can support early colonizers like midges (Obolewski et al., 2015). While midges are relatively poor flyers, the short flight distance and lack of predators in the floodplain pools allows them to establish (Obolewski et al., 2015). Connectivity has been found to be important to lentic species, but high swim ability mitigates the impact of channel distance and high flight ability mitigates the impact of flooding height (Ishiyama et al., 2014). This explains why mollusks were the most highly impacted group in my study and many others as they are neither flyer nor good swimmers (Ishiyama et al., 2014; Patrick et al., 2014; and Obolewski et al., 2015). Dispersal ability was useful in determining which organisms made it to the more disconnected and far away floodplain wetlands and ultimately, that affected the diversity at those sites.

The complex nature of organism's life history is likely obscuring the trends between connectivity and dispersal ability in this study. In particular, the trait database used to classify organisms' dispersal ability does not consider all types of active and passive dispersal. Organisms like crustaceans and mollusks, which were considered to be non-flyers in this study, have been shown to actively disperse via the feathers of mallards and the fur of muskrats (Bilton et al., 2001). Organisms can also be moved passively through flood events as mentioned previously but also, poor fliers can be passively dispersed by the wind. For example, biting midges have been shown to be transported long distances through passive wind transport in disease ecology papers (e.g. Ducheyne

et al., 2007). Other means of dispersal include wind dispersal of eggs and vector-mediated dispersal, which can greatly increase dispersal distance but could lead to terrestrial deposition (Bilton et al., 2001). Inclusion of these additional dispersal methods into existing databases could help untangle the complex relationship between dispersal ability and connectivity, which can then be applied to models to determine various species survival and persistence under varying connectivity scenarios.

### Connectivity and Food Web Dynamics

If connectivity affects diversity through dispersal ability, it is reasonable to assume it must have consequences for food web structure as well. I used stable isotope analysis to probe this necessary consequence of organismal persistence and diversity in floodplain wetlands. My preliminary hypothesis in this regard was that more connected (and therefore diverse) units would show evidence of more elaborate food web structure and that this might be detectable using nitrogen and (secondarily) carbon isotopes. That is, I hoped to assess if connectivity affected food web dynamics, either directly or indirectly, through reductions in diversity. While some inferences can be made from my analysis, the results were somewhat inconclusive due to methodological and sampling limitations. Connected sites did have higher delta nitrogen values than their adjacent diked units, indicative of more trophic processing and longer food chains in ecological studies (Peterson and Fry, 1987; Vanderklift and Ponsard, 2003). However, we were unable to characterize and therefore control for potential variations at the base of the food chains in each pair of sites with contrasting connectivity. Because base of the food web was not successfully characterized isotopically, the relative trophic complexity of adjacent sites could not be directly compared. Despite initial expectations, we were not able to use

Amphipods to adequately represent the base of the odonates food chain due to significant site differences in their observed carbon isotope compositions. These differences suggested that the gammarids and odonates did not share a common (and typically conserved) basal carbon source across all sites. This difference likely reflects differences in the microhabitats used by the two groups. Gammarids are associated with dead and decaying matter on the substrate, which in wetlands is typically near or at the transition to highly reduced soil chemistry. Both Coenagrionids and aeshnids in wetlands are associated with perched habitats in the upper portion of the water column where redox is higher and light penetration better. In retrospect, the likelihood of differential contributions of inorganic and organic sources of carbon to the base of the food chain seems apparent. More negative delta C values across both connected and dikes sites for gammarids seem to support this interpretation.

Without a primary consumer to characterize the base of the odonate food web, I used comparisons of the isotopic niche space as a relative, but still useful, approach to evaluating differences related to connectivity. The niche space (2D space created using both isotopic values) of dragonflies was consistently larger than damselflies showing that dragonflies are integrating carbon and nitrogen from a more diverse diet (Figure 18). While there was no significant statistical difference between the two groups when analyzing the isotope individually, it was interesting to find that damselflies occasionally had higher nitrogen values, an indication of eating at a higher trophic level. A potential reason for this could be that damselflies are more likely to eat micro-crustaceans and small midges feeding on algae that are enriched in nitrogen 15, while larger aeshnids may focus more on larger benthic and epibenthic invertebrates more likely to be omnivores, shredders or collector-gathering taxa feeding a heterogenous sources. Other studies have

found that even slight changes in connectivity can alter food web structure (Vinagre et al. 2011). Much of the variation seen in the isotope data probably cannot be solely attributed to food chain length and is likely differing basal sources of carbon and nitrogen in the different units. The large variations between sites, while very interesting make interpretation difficult.

Analysis of stable isotopes in ecological studies regarding connectivity issues have been limited (Vinagre et al. 2011; Howe and Simenstad, 2015), but given the power of the tool, it should be considered more frequently. The use of stable isotopes in planning hydrologic restorations could help determine if transfers of organisms and energy are occurring and if more natural elemental cycling has been restored.

#### The importance of connectivity in wetland restoration

Optimization is becoming a key aspect of restoration projects trying to maximize biological and economic returns (Diefenderfer et al., 2012). Wetland and refuge managers have much to consider when protecting wetland habitats. From everyday maintenance of complex biological systems to monitoring and protection of key wildlife species to managing invasive plant species, many things take away from a limited fund of already stretched dollars. Managers can benefit from the findings of this study because they indicate a relationship with connectivity and macroinvertebrate biodiversity, which may expand beyond and help better manage all the biota present at the Shiawasee Refuge. The utility of this study can focus managers on hydrology to increase their understanding of how their particular wetlands work, moving toward an increasingly system based management technique. The key to increasing diversity will be understanding the

diversity of systems and scenarios present, which will call for different management methods and varying levels of connectivity.

While there is a potential for many benefits, managers must also be cognizant of potential negative impacts on biodiversity due to hydrologic connectivity on habitat health and stability (e.g. Jackson and Pringle, 2010; Corea Ayram et al., 2016; Dou et al., 2016). Therefore, it is important to consider hydrologic connectivity in management and design projects for wetland restoration. Nutrient cycling, dissolved oxygen, and biodiversity can all be positively impacted by connectivity (Amoros and Bornette, 2002; Bunn and Arthington, 2002; Paillex et al., 2013) while transmission of pollution and invasive species can be major negative impacts to wetland stability (Herrick and Wolf, 2005; Jackson and Pringle, 2010). The task of balancing invasive species management, wildlife protection, and budget constraints falls on wetland managers who will have to rely on affordable and easy to enact techniques. This research is a small part of what can and needs to be developed to understand and manage the interconnections between hydrologic connectivity and biodiversity.

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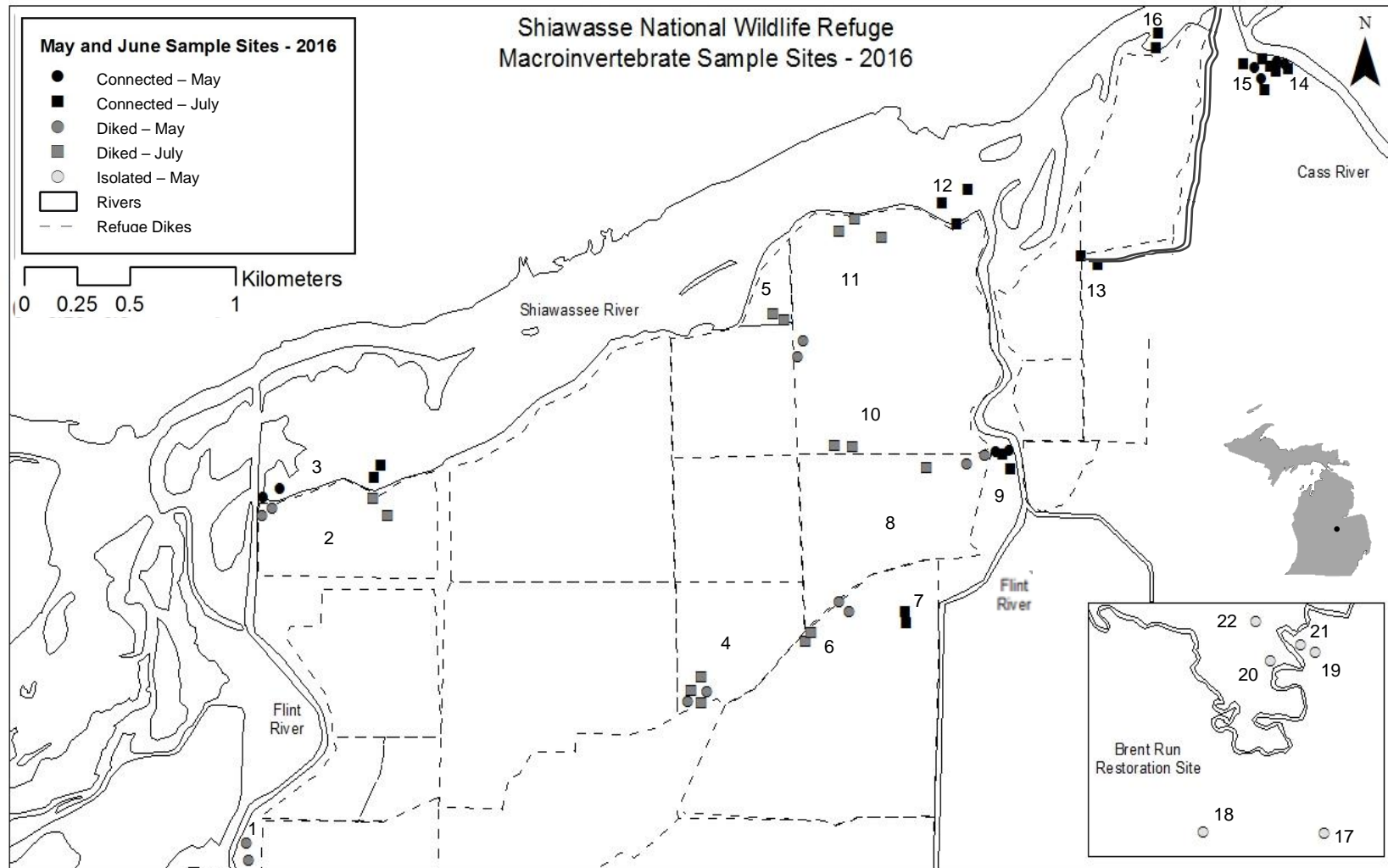
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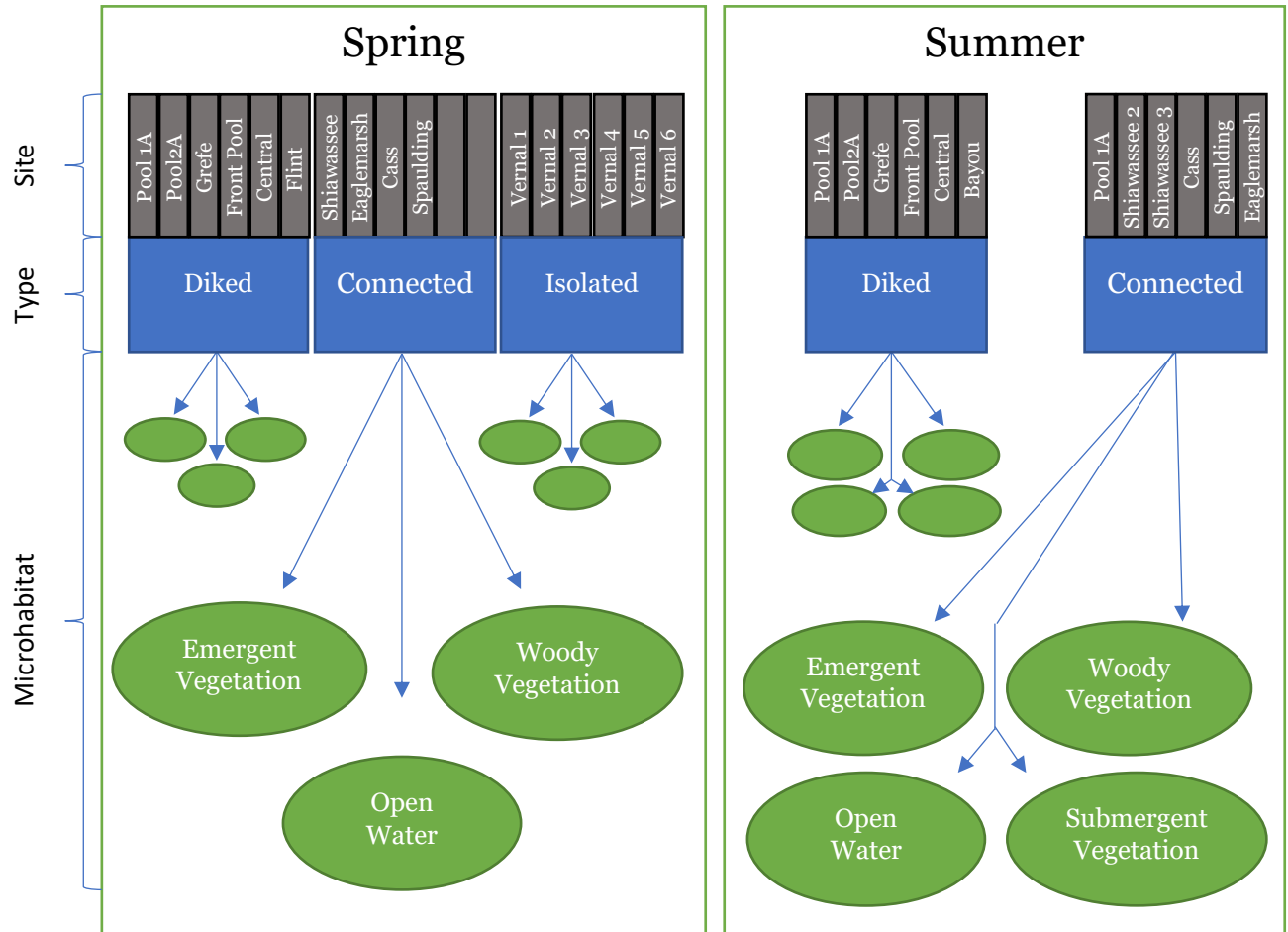
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## Figures and Tables

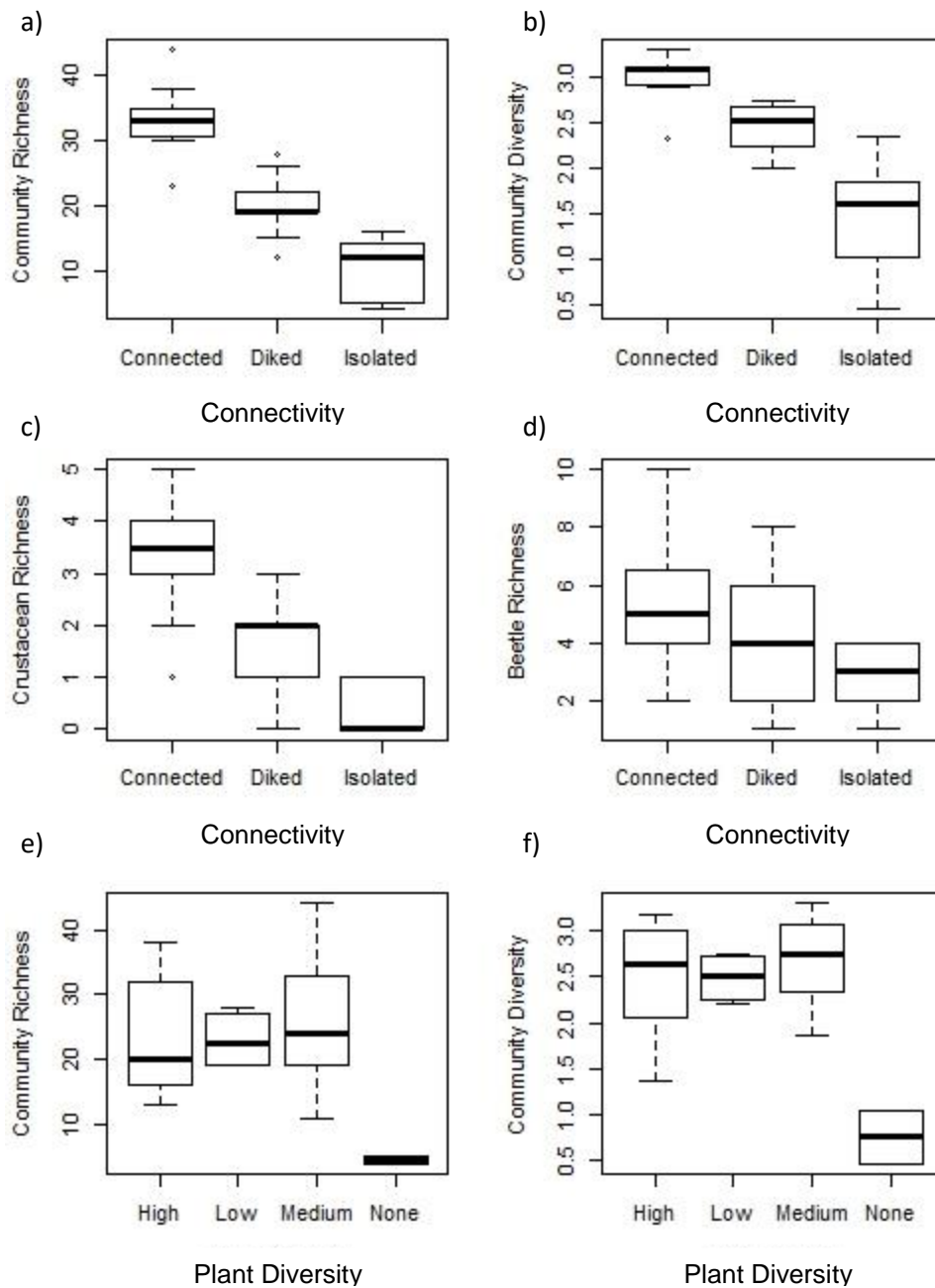


**Figure 1: Refuge sampling sites.** Study sites for 2016 Macroinvertebrate Sample. Main map is *Connected* and *Diked* sites in Shiawassee National Wildlife Refuge near Saginaw, MI and small inset is *Isolated* sites in Montrose, MI near Brent Run River. See Table 1 for description of sites based on numbers on map.



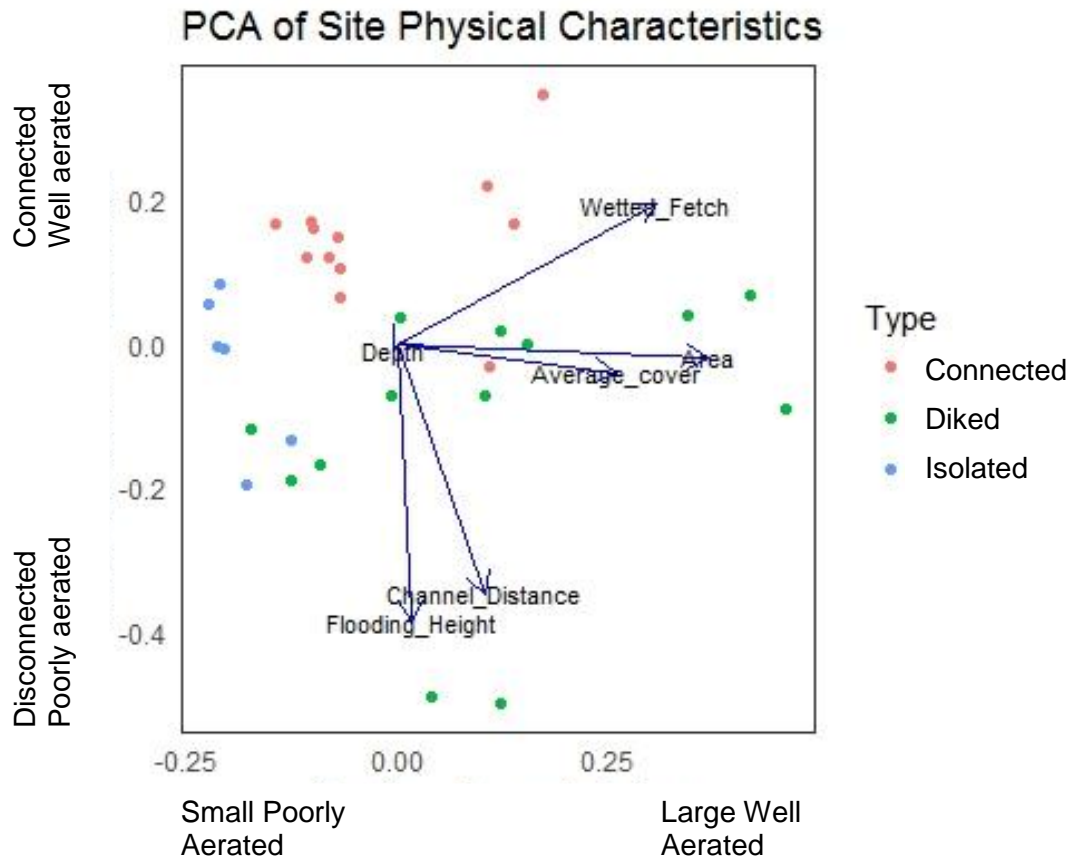
**Figure 2: Sampling diagram.** Macroinvertebrate sampling setup.

## Macroinvertebrates, Connectivity, and Plant Diversity

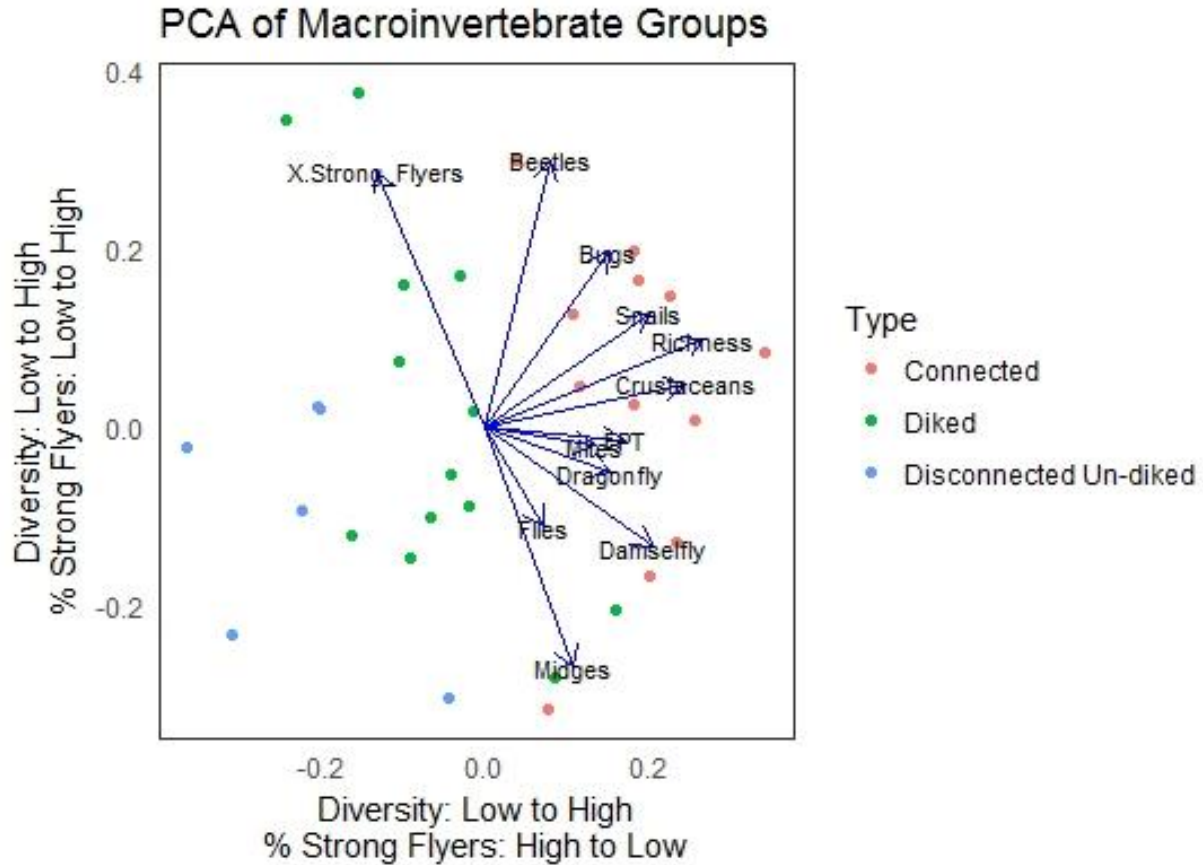


**Figure 3:** Boxplots showing various relationships between diversity, connectivity, and vegetation: a & b are total richness and diversity, c & d are crustacean and beetle richness, e & f show total macroinvertebrate richness and diversity related to plant diversity. \*Plots e & f had only 2 samples had no plant diversity and both were found at the isolated sites of the restoration project.

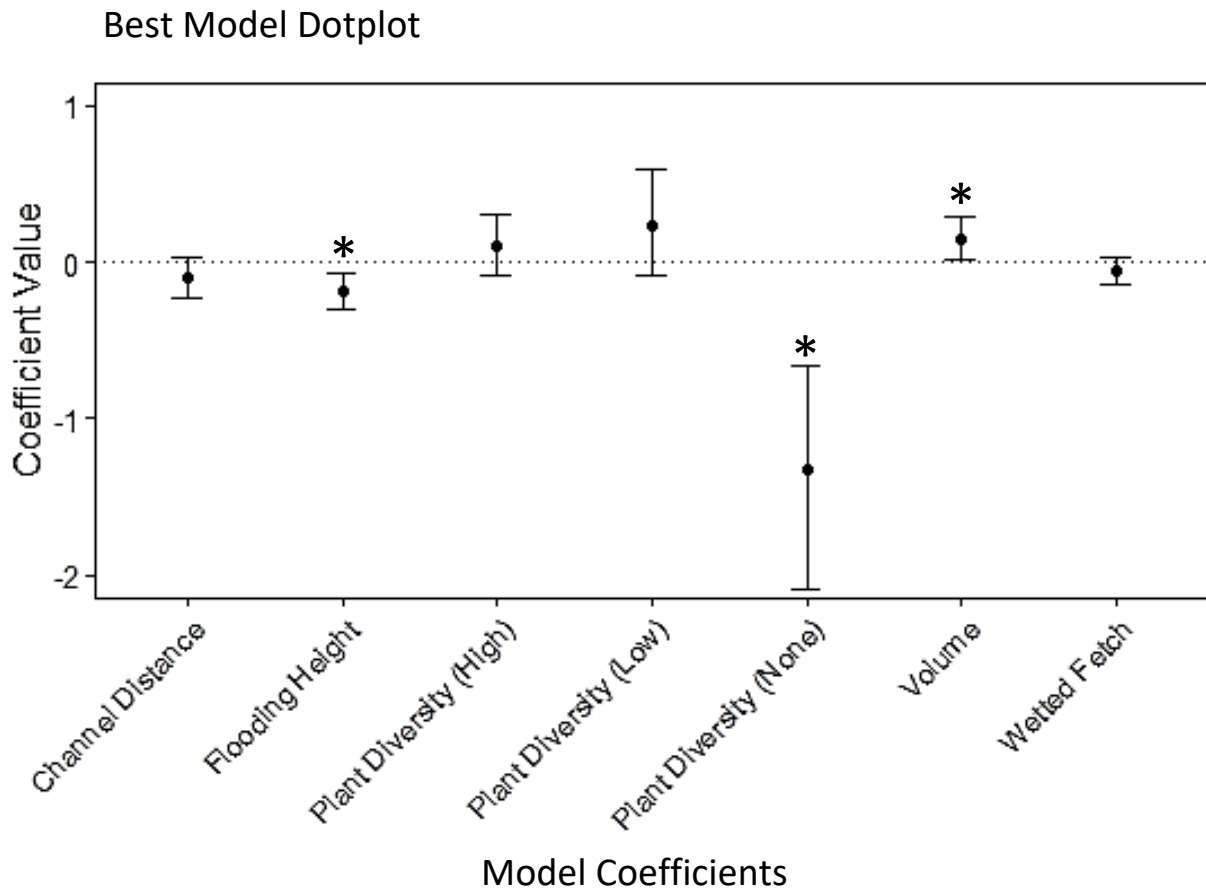




**Figure 4:** Principle component analysis of site physical characteristics. First two components (38% and 18% variance) were representative and important using the broken stick method. Sites to the right are larger, more densely vegetated, and better aerated compared to the sites on the left. Sites on the upper half of the graph are also better aerated and more connected hydrologically compared to the sites on the lower half of the graph.

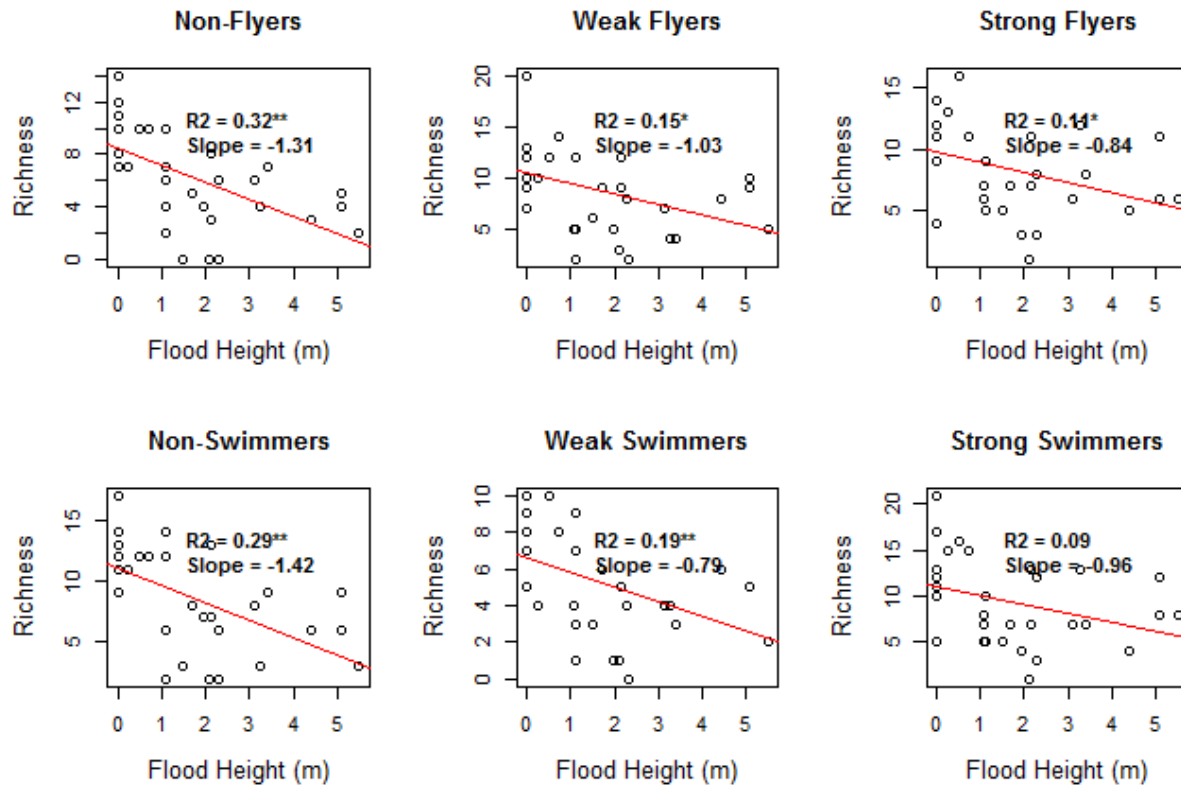


**Figure 5:** Principle component analysis using macroinvertebrate groups. Only first 2 components were representative using the broken stick method. The first component (36% variance) on the x-axis goes from sites with low diversity in all groups represented in the eigen vectors to high diversity and decreased percentage of strong flyer species. The second component (18% variance) along the y-axis, the bottom of the plot space sites are represented by species intolerant to low oxygen and decreased percentage of strong flyers to the top where the species are highly tolerant of dissolved oxygen (beetles and true bugs) and stronger flyers.

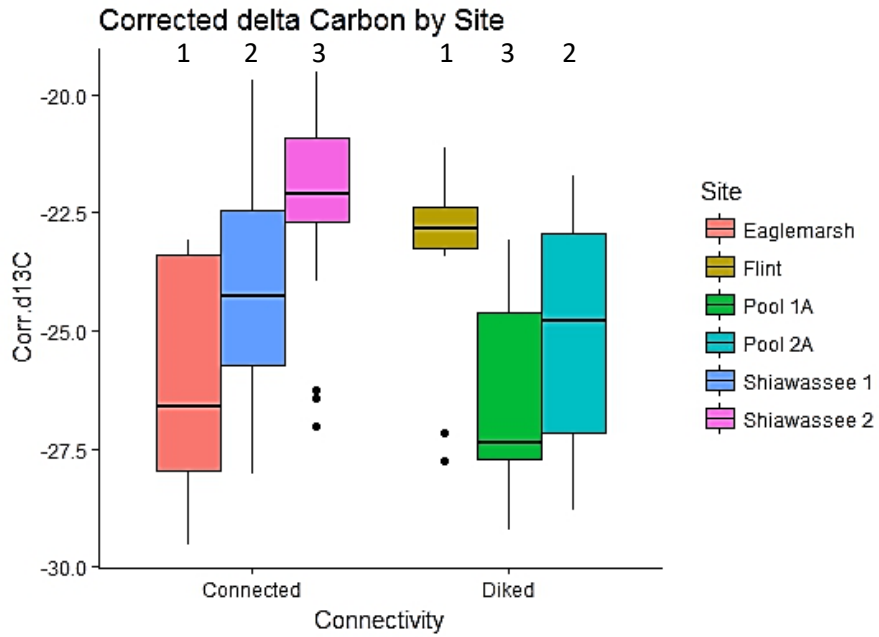


**Figure 6: Best Model Dotplot.** Shows the scaled coefficient values and 95% confidence interval estimated from the GLMM model predicting macroinvertebrate diversity outlined in Equation 1. \* indicates significance at  $p < 0.05$ .

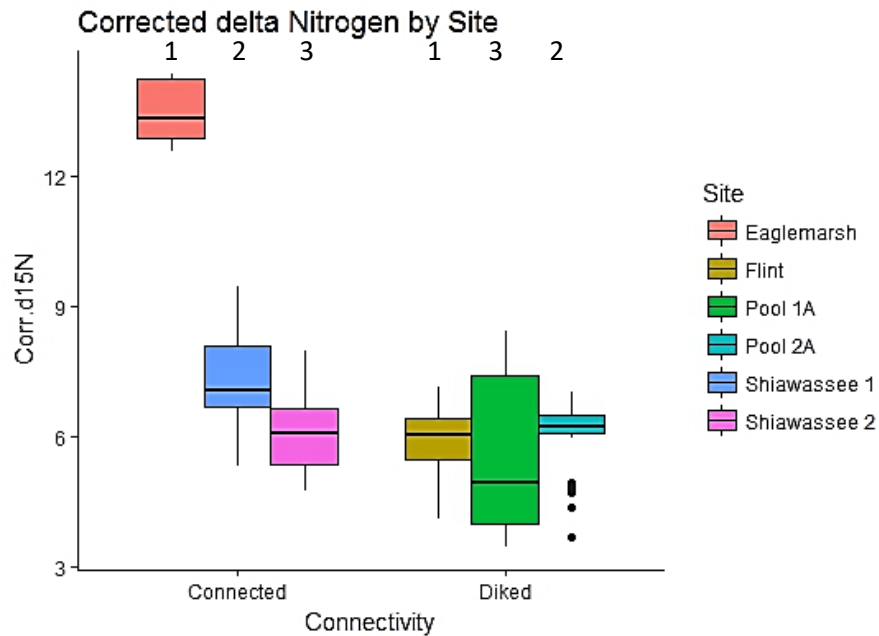
## Impact of Connectivity based on Dispersal Ability



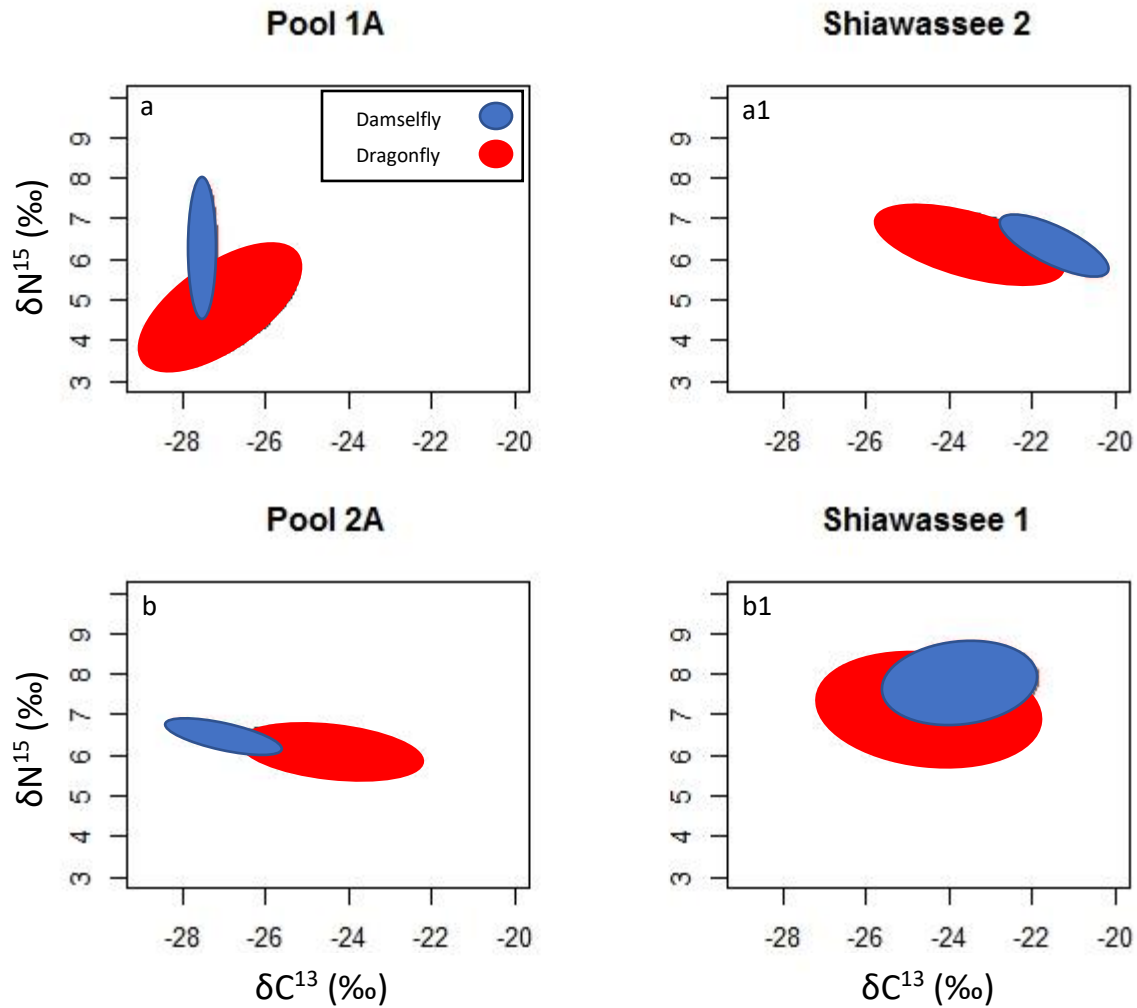
**Figure 7: Dispersal and Flooding Height Trends.** Taxa richness declined with increasing Flooding Height (water height required to flood the wetland unit) in all six dispersal categories. R<sup>2</sup> and trend lines are displayed. Significance level is denoted by asterisks (\*  $\alpha < 0.05$ , \*\*  $\alpha < 0.001$ ).



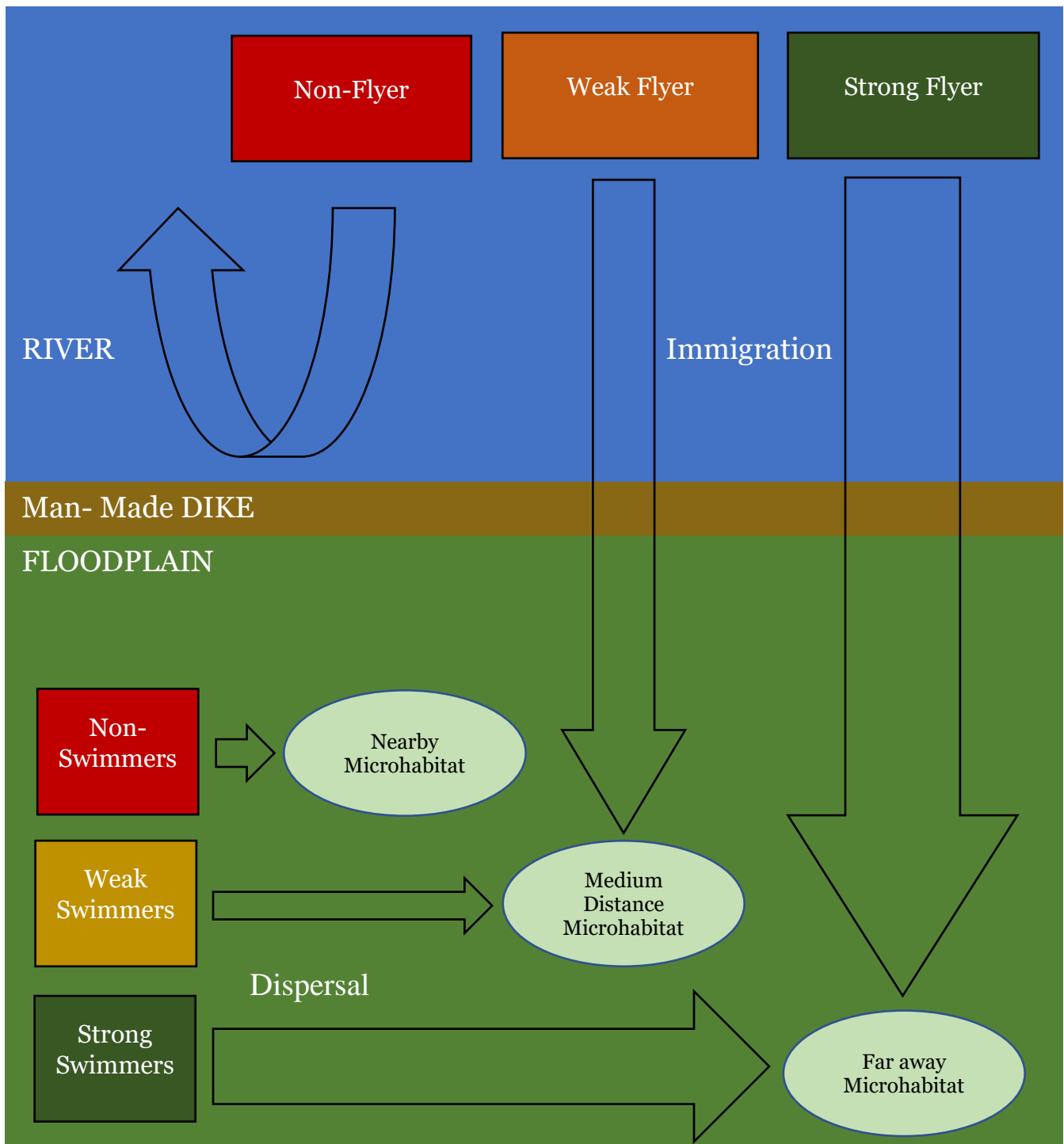
**Figure 8:** Boxplot showing the community corrected delta carbon values for each site in the two connectivity categories. Pairs indicated above boxes.



**Figure 9:** Boxplot showing the community corrected delta nitrogen values for each site in the two connectivity categories. Pairs indicated above boxes



**Figure 10: Niche ellipse space plots.** Ellipse spaces of odonate predators by paired diked (a, b) and connected (a1, b1) sites. Niche space was calculated for dragonflies and damselflies using the SIBER package in R.



**Figure 11: Conceptual Diagram.** Shows how dispersal impacts and structures community diversity in diked floodplains. Macroinvertebrates with stronger capabilities of flight can cross man-made dikes and immigrate into various microhabitats. Within the floodplain swim ability factors into which microhabitats organisms disperse to.

**Table 1: Site Characteristics.** Naming structure and characteristics of all sites as identified on Figure 1. Sites with an \* and ^ are paired *connected/diked* sites for the stable isotope analysis.

Site Name	# on Fig. 1	Connectivity	GPS Coordinates	Weighted Richness	Area (hectares)
Flint Swamp	1	Diked	N43.349, W-84.006	14.40	1.8
Pool 2A^	2	Diked	N43.348, W-84.013	32.43	46.5
Shiawassee 1^	3	Connected	N43.344, W-84.023	30.72	57.1
Central Pool	4	Diked	N43.357, W-84.000	22.60	35.5
Front Pool	5	Diked	N43.367, W-83.467	12.58	7.7
Bayou North	6	Diked	N43.379, W-83.983	19.81	12.1
Bayou Marsh	7	Connected	N43.344, W-84.023	18.66	102.0
Grefe	8	Diked	N43.353, W-84.051	29.46	64.1
Spaulding Wetland	9	Connected	N43.351, W-84.008	35.48	1.5
Pool 1A South	10	Diked	N43.379, W-83.983	11.55	21.9
Pool 1A*	11	Diked	N43.376, W-83.981	23.95	106.1
Shiawassee 2*	12	Connected	N43.337, W-84.052	15.06	5.6
Eaglemarsh West	13	Connected	N43.376, W-83.983	27.68	38.0
Cass	14	Connected	N43.379, W-83.981	36.47	5.2
Eaglemarsh North	15	Connected	N43.367, W-83.994	42.88	14.2
Shiawassee 3	16	Connected	N43.363, W-84.016	25.84	1.9
Bowl Vernal Pool	17	Isolated	N43.166, W-83.838	5.00	0.2
Back Vernal Pool	18	Isolated	N43.165, W-83.830	4.00	0.1
Old Wetland Pool 1	19	Isolated	N43.168, W-83.839	14.00	0.01
Center Vernal Pool	20	Isolated	N43.169, W-83.841	11.00	0.02
Old Wetland Pool 2	21	Isolated	N43.169, W-83.840	16.00	0.02
Landfill Pool	22	Isolated	N43.170, W-83.842	13.00	0.01

**Table 2: Vegetation codes.** Coding for plant variables

Variable	Vegetation Codes			
	0	1	2	3
Plant Diversity	0 taxa 0-10%	1 taxa 11-45%	2-3 taxa 46-90%	>3 taxa 91-100%
Vegetation Cover				



**Table 3: Variation across Connectivity classes.** Means with standard deviations in parenthesis for key features of different site types. Connectivity parameters in bold.

Variable	<u>Connected Floodplains</u>		<u>Diked Floodplains</u>		<u>Isolated Floodplain</u>		Units
<b>Channel Distance</b> <sup>P</sup>	<b>142.1</b>	<b>(126.7)</b>	<b>840.8</b>	<b>(594.2)</b>	<b>61.8</b>	<b>(64.5)</b>	<b>m</b>
<b>Flight Distance</b> <sup>P</sup>	<b>125.0</b>	<b>(179.1)</b>	<b>499.6</b>	<b>(466.0)</b>	<b>61.8</b>	<b>(64.5)</b>	<b>m</b>
<b>Flooding Height</b> <sup>P</sup>	<b>0.3</b>	<b>(0.6)</b>	<b>2.5</b>	<b>(1.4)</b>	<b>2.8</b>	<b>(1.7)</b>	<b>m</b>
Area <sup>P</sup>	25.3	(31.9)	54.6	(46.4)	0.04	(0.06)	ha
Water Temperature	24.8	(1.4)	23.7	(2.1)	-	(-)	°C
Dissolved Oxygen <sup>P</sup>	4.2	(2.2)	1.7	(0.9)	-	(-)	mg/l
Total Dissolved Solids	0.5	(0.1)	0.4	(0.1)	-	(-)	g/l
Percent Cover	20.5	(13.1)	30.1	(27.6)	16.8	(18.9)	%
Abundance <sup>P</sup>	143.8	(46.8)	104.9	(37.0)	98.8	(30.0)	Richness
Richness <sup>P</sup>	30.3	(5.0)	20.2	(4.3)	13.2	(7.8)	Richness
Rare Species	1.2	(0.6)	1.1	(0.6)	1.2	(0.8)	Richness
Strong Flyer <sup>P</sup>	11.5	(3.0)	7.3	(2.4)	4.5	(2.2)	Richness
Weak Flyer <sup>P</sup>	12.0	(3.2)	7.4	(3.2)	4.8	(2.1)	Richness
Non-Flyer <sup>P</sup>	9.8	(2.1)	5.5	(1.9)	1.2	(1.3)	Richness
Strong Swimmer <sup>P</sup>	13.3	(4.0)	8.1	(2.9)	4.7	(2.6)	Richness
Weak Swimmer <sup>P</sup>	7.4	(2.0)	4.6	(1.9)	2.2	(2.1)	Richness
Non-Swimmer <sup>P</sup>	12.6	(2.0)	7.5	(3.2)	3.7	(1.9)	Richness
Odonata <sup>P</sup>	3.6	(1.1)	2.2	(1.6)	1.4	(1.4)	Richness
Diptera <sup>P</sup>	2.3	(1.7)	0.7	(0.6)	2.8	(0.7)	Richness
Coleoptera	5.4	(2.2)	4.2	(2.4)	3.0	(1.1)	Richness
Hemiptera <sup>P</sup>	5.8	(2.9)	3.8	(1.8)	2.2	(1.6)	Richness
EPT* <sup>P</sup>	2.1	(1.0)	1.0	(1.0)	0.7	(0.8)	Richness
Crustacean <sup>P</sup>	3.4	(1.2)	1.5	(0.8)	0.3	(0.5)	Richness
Gastropod <sup>P</sup>	3.7	(0.9)	2.7	(1.0)	0.3	(0.5)	Richness
Diversity <sup>P</sup>	3.0	(0.24)	2.4	(0.26)	1.49	(0.67)	Shannon
Odonata Diversity <sup>P</sup>	0.78	(0.59)	0.38	(0.60)	0.16	(0.42)	Shannon
Coleoptera Diversity	0.78	(0.45)	0.57	(0.55)	0.77	(0.38)	Shannon
Diptera Diversity	0.80	(0.54)	0.34	(0.38)	0.70	(0.32)	Shannon
Hemiptera Diversity	0.89	(0.65)	0.60	(0.52)	0.49	(0.62)	Shannon
ET* Diversity <sup>P</sup>	0.10	(0.16)	0.03	(0.09)	0.04	(0.01)	Shannon
Crustacean Diversity <sup>P</sup>	0.70	(0.39)	0.13	(0.24)	0	(0)	Shannon
Gastropod Diversity <sup>P</sup>	0.77	(0.37)	0.42	(0.45)	0	(0)	Shannon

\* is the combined families *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (no *Plecopterans* were found).

<sup>P</sup> significant ANOVA test and t-test

**Table 4: Correlation matrix.** Matrix of all variables analyzed with highly correlated variables color coded. Light green = 0.5 – 0.75 correlation, dark green = 0.76 – 1.0 correlation, and red = -0.5 – -0.75.

	Wetted Fetch	Channel Distance	Flooding height	Depth	Area	Average Cover	Richness	Shannon Diversity	Odonate	Damselfly	Dragonfly
Wetted Fetch	1.000										
Channel_dist	-0.064	1.000									
Flooding_height	-0.305	0.520	1.000								
Depth	-0.005	0.105	-0.076	1.000							
Area	0.523	0.206	0.069	0.010	1.000						
Avecover	0.182	0.048	0.100	0.058	0.355	1.000					
Richness	0.233	-0.147	-0.535	0.083	0.056	0.081	1.000				
ShanInd	0.282	0.000	-0.354	0.116	0.200	0.334	0.905	1.000			
Odonate	0.209	-0.117	-0.450	0.220	-0.048	0.065	0.720	0.673	1.000		
Damsel	0.304	-0.072	-0.406	0.114	-0.018	0.084	0.621	0.610	0.906	1.000	
Dragon	-0.076	-0.135	-0.289	0.296	-0.077	-0.004	0.515	0.429	0.636	0.249	1.000
Beetle	0.012	0.021	-0.069	0.256	-0.041	0.063	0.475	0.453	0.016	0.081	-0.111
Midge	-0.374	-0.040	-0.038	0.096	-0.143	-0.133	0.245	0.182	0.486	0.397	0.386
Surface	0.155	-0.102	-0.246	0.139	0.156	0.096	0.761	0.702	0.236	0.149	0.268
Shells	0.113	0.106	-0.435	0.124	0.076	-0.017	0.754	0.736	0.434	0.385	0.290
EPT	0.264	-0.147	-0.342	0.010	0.291	0.278	0.584	0.500	0.442	0.463	0.167
Bug	0.230	-0.143	-0.250	0.032	0.284	0.097	0.669	0.622	0.241	0.082	0.401
Mite	0.376	-0.176	-0.295	0.020	-0.054	-0.081	0.417	0.398	0.373	0.348	0.219
Fly	-0.211	-0.307	-0.197	0.022	-0.399	0.005	0.212	0.185	0.253	0.293	0.045
Crab	0.270	-0.201	-0.574	0.071	-0.063	-0.022	0.848	0.709	0.682	0.610	0.449
SwimN	0.120	-0.074	-0.559	0.138	-0.089	-0.029	0.863	0.775	0.771	0.686	0.512
SwimW	0.298	-0.094	-0.471	0.242	0.086	0.072	0.855	0.776	0.853	0.744	0.595
SwimS	0.207	-0.188	-0.345	0.095	0.148	0.157	0.825	0.751	0.315	0.247	0.270
FlyerN	0.305	-0.129	-0.589	0.100	0.036	-0.036	0.897	0.804	0.671	0.595	0.450
FlyerW	0.094	-0.061	-0.419	0.157	0.016	0.058	0.847	0.757	0.813	0.756	0.481
FlyerS	0.214	-0.195	-0.377	-0.051	0.095	0.188	0.835	0.775	0.353	0.227	0.392
PerFlyerS	-0.043	-0.142	0.203	-0.259	0.051	0.104	-0.260	-0.222	-0.574	-0.598	-0.223

<i>Beetle</i>	<i>Midge</i>	<i>Surface</i>	<i>Shells</i>	<i>EPT</i>	<i>Bug</i>	<i>Mite</i>	<i>Fly</i>	<i>Crab</i>	<i>Non-Swimmer</i>	<i>Weak Swimmer</i>	<i>Strong Swimmer</i>	<i>Non-Flyer</i>	<i>Weak Flyer</i>	<i>Strong Flyer</i>	<i>Percent Strong Flyer</i>
1.000															
-															
0.261	1.000														
0.728	-0.135	1.000													
0.459	0.078	0.543	1.000												
0.142	0.213	0.356	0.185	1.000											
0.265	-0.055	0.844	0.412	0.359	1.000										
-															
0.067	-0.031	0.169	0.299	0.093	0.284	1.000									
0.037	0.298	-0.066	0.021	0.212	0.107	0.180	1.000								
0.361	0.228	0.500	0.661	0.515	0.380	0.377	0.129	1.000							
0.190	0.455	0.417	0.785	0.412	0.392	0.495	0.366	0.739	1.000						
0.246	0.335	0.463	0.542	0.599	0.394	0.416	0.113	0.874	0.748	1.000					
0.690	-0.095	0.960	0.561	0.507	0.828	0.185	0.050	0.604	0.473	0.536	1.000				
0.347	0.146	0.581	0.837	0.406	0.513	0.589	0.047	0.895	0.852	0.825	0.635	1.000			
0.188	0.560	0.467	0.514	0.680	0.458	0.249	0.383	0.664	0.826	0.804	0.564	0.655	1.000		
0.712	-0.108	0.933	0.609	0.402	0.766	0.249	0.097	0.635	0.539	0.570	0.941	0.672	0.502	1.000	
0.411	-0.568	0.267	0.258	0.280	0.117	0.296	0.073	0.330	-0.525	-0.453	0.197	0.361	-0.540	0.260	1.000

**Table 4:** Correlation Matrix: 2 of 2.

**Table 5: Principle Component Analysis Summary Statistics.** Only the first 4 components are shown as they represent 70-80% of the variance.

Physical Variable PCA	Comp. 1	Comp. 2	Comp. 3	Comp. 4
Prop. of Variance	0.29	0.27	0.18	0.13
Loadings:				
Area	0.664			0.171
Average Cover	0.468		-0.279	-0.790
Channel Distance	0.186	-0.624	0.228	0.285
Depth			0.914	-0.364
Flooding Height		-0.694	-0.142	
Wetted Fetch	0.552	0.349	0.106	0.364
<b>Biological Variable PCA</b>				
Prop. of Variance	0.33	0.20	0.11	0.09
Loadings:				
Richness	-0.498			
Damselfly	-0.253	0.23	0.368	
Dragonfly	-0.281		0.137	-0.498
Beetle	-0.134	-0.418	-0.203	0.129
Midge	-0.133	0.434	-0.527	
Snail	-0.283			0.608
EPT	-0.217	0.319	0.203	-0.391
Bug	-0.268	-0.330	-0.300	-0.174
Mite	-0.214	0.133	0.339	0.223
Fly	-0.195	0.475	-0.418	
Crustaceans	-0.365		0.288	0.284
% Strong Flyer	-0.396	-0.343	-0.126	-0.176

**Table 6: Model Results.** Generalized Mixed Effect (GLMM) models run at various scales.

Equation	AIC	R <sup>2</sup>	Significant Variables	Parameter Coefficient	P-Value
<u>Site Level</u>					
$R = \alpha_p + FH*\beta + WF*\beta_2 + CD*\beta_4 + \ln(V)*\beta_5 + S$	<b>217.1</b>	<b>0.85</b>	A	3.06	< 0.0001
			FH	-0.19	0.001
			P <sub>None</sub>	-3.67	0.0002
			ln(V)	0.15	0.03
$R = \alpha + FH*\beta + WF*\beta_2 + PC*\beta_3 + CD*\beta_4 + \ln(V)*\beta_5 + (1 S)$	239.9	0.72	A	3.10	< 0.001
			FH	-0.19	0.002
			ln(V)	0.22	0.0001
<u>Microhabitat Level</u>					
$R = \alpha + FH*\beta + WF*\beta_2 + \ln(A)*\beta_3 + (1 Veg)$	375.7	0.39	A	2.69	< 0.0001
			FH	-0.22	<0.0001
			ln(A)	-0.09	0.0213
$R = \alpha + FH*\beta + WF*\beta_2 + \ln(A)*\beta_3 + (1 S)$	381.2	0.46	A	2.73	< 0.0001
			FH	-0.23	<0.0001
			WF	-0.10	0.0116
			ln(A)	0.09	0.029
<u>Nested Microhabitats within Sites</u>					
$R = \alpha + FH*\beta + WF*\beta_2 + A*\beta_3 + (1 S/Si/Veg)$	378.7	0.24	$\alpha$	2.71	< 0.0001
			FH	-0.20	0.0004

Abbreviations: A – Area, CD – Channel Distance, FH – Flooding Height, P – Plant Diversity, PC – Percent Vegetation Cover, R – Macroinvertebrate Richness, S – Season, Si - Site, Veg – Vegetation Type, V – Volume, and WF – Wetted Fetch

**Table 7: Best model.** Selected for analysis based on lowest AIC score and significance to biology. Model:  $R = \alpha + FH*\beta + WF*\beta_2 + P*\beta_3 + CD*\beta_4 + \ln(V)*\beta_5 + (1|S)$ . Bolded coefficients are significant.

Coefficient	Abbreviation	Estimate	95% Confidence Interval	P-Value
<b>Intercept</b>	$\alpha$	3.06	2.82 – 3.23	<0.0001
<b>Flooding Height</b>	FH	-0.19	-0.301 – -0.074	0.001
<b>Volume</b>	V	0.15	0.018 – 0.285	0.03
Channel Distance	CD	-0.10	-0.231 – 0.038	0.17
Wetted Fetch	WF	-0.05	-0.144 – 0.031	0.22
<b>Plant Diversity (None)</b>	P <sub>None</sub>	-1.32	-2.088 – -0.667	0.0002
Plant Diversity (Low)	P <sub>Low</sub>	0.24	-0.083 – 0.597	0.21
Plant Diversity (Medium)	P <sub>Medium</sub>	0.105	-0.081 – 0.307	0.32
Season (Summer)	S	0.169	-0.001 – 0.304	-

**Table 8: Dispersal Model Results.** Generalized Mixed Effect (GLMM) run for the various dispersal ability categories. Equation for all models:  $f(x) = \alpha + FH*\beta + WF*\beta_2 + CD* \beta_4 + \ln(V)* \beta_5 + S$ , where x = Non-,weak, or strong flyer/swimmer.

Dispersal Category	AIC	R <sup>2</sup>	Significant Variables	Parameter Coefficient	P-Value
Non-Flyer	165.9	0.68	$\alpha$	1.71	< 0.0001
			FH	-0.53	0.0016
			Ln(V)	0.36	0.00248
Weak Flyer	156.6	0.44	$\alpha$	2.12	< 0.001
			FH	-0.21	0.0292
			ln(V)	0.21	0.0354
Strong Flyer	167.4	0.38	$\alpha$	2.09	< 0.0001
			FH <sup>NS</sup>	-0.05	0.619
Non-Swimmer	170.3	0.59	$\alpha$	2.10	< 0.0001
			FH	-0.38	0.0003
Weak Swimmer	147.3	0.48	$\alpha$	2.71	< 0.0001
			FH <sup>NS</sup>	-0.22	0.0769
			Ln(V)	0.30	0.0181
Strong Swimmer	179.8	0.45	$\alpha$	2.19	< 0.0001
			FH <sup>NS</sup>	-0.02	0.832
			CD	-0.20	0.0446
			Ln(V)	0.23	0.0206

Abbreviations: A – Area, CD – Channel Distance, FH – Flooding Height, P – Plant Diversity, PC – Percent Vegetation Cover, R – Macroinvertebrate Richness, S – Season, Si - Site, Veg – Vegetation Type, V – Volume, and WF – Wetted Fetch

<sup>NS</sup> Non-significant flooding height coefficient

**Table 9: Summary Isotope Data.** Means for data collected in stable isotope study. Standard deviations are in parentheses.

<b>Dragonfly</b>					
<u>Site</u>	<u>Connectivity</u>	<u>N</u>	<u>Delta N</u>	<u>Delta C</u>	<u>Weight</u>
Shiawassee 1	Connected	9	7.19 (1.31)	-24.65 (2.52)	48.45 (22.81)
Shiawassee 2	Connected	11	6.52 (0.73)	-23.39 (2.22)	25.49 (17.61)
Pool 1A	Diked	10	4.76 (1.44)	-27.00 (1.81)	40.88 (30.44)
Pool 2A	Diked	15	6.12 (0.61)	-24.48 (2.2)	92.93 (96.53)
Eaglemarsh	Connected	3	13.18 (0.25)	-28.04 (1.79)	135.99 (83.78)
Flint	Diked	4	5.22 (0.99)	-25.11 (2.75)	67.00 (57.68)
<b>Damselfly</b>					
<u>Site</u>	<u>Connectivity</u>	<u>N</u>	<u>Delta N</u>	<u>Delta C</u>	<u>Weight</u>
Shiawassee 1	Connected	10	7.77 (1.01)	-23.69 (1.85)	8.89 (3.73)
Shiawassee 2	Connected	13	6.31 (0.72)	-21.49 (1.25)	6.53 (2.69)
Pool 1A	Diked	12	6.19 (1.66)	-27.47 (0.28)	7.98 (2.62)
Pool 2A	Diked	10	6.47 (0.33)	-26.88 (1.34)	13.91 (4.01)
Eaglemarsh	Connected	7	14.25 (0.09)	-27.51 (0.65)	11.08 (0.76)
Flint	Diked	11	6.15 (0.64)	-22.65 (0.66)	8.89 (2.39)
<b>Amphipod</b>					
<u>Site</u>	<u>Connectivity</u>	<u>N</u>	<u>Delta N</u>	<u>Delta C</u>	<u>Weight</u>
Shiawassee 1	Connected	2	6.28 (0.41)	-24.49 (0.30)	20.42 (0.54)
Shiawassee 2	Connected	9	5.27 (0.49)	-21.61 (0.81)	8.29 (3.07)
Pool 1A	Diked	6	5.13 (2.28)	-24.05 (0.54)	5.37 (1.96)
Pool 2A	Diked	4	4.46 (0.57)	-22.33 (0.47)	15.00 (0)
Eaglemarsh	Connected	6	12.79 (0.18)	-23.28 (0.16)	14.91 (6.85)
Flint	Diked	0	-	-	-

**Table 10: Summary statistics for SIBER.** Analysis of paired connectivity sites (Diked Pool 1A with Connected Shiawassee 2 and Diked Pool 1A with Connected Shiawassee 1). TA = total area of hull, SEA = standard ellipse area, and SEA<sub>C</sub> = standard ellipse area corrected for sample size.

Paired Sites	Pool1 Dragonfly	Pool1 Damselfly	Shia.2 Dragonfly	Shia.2 Damselfly	Pool2 Dragonfly	Pool2 Damselfly	Shia.1 Dragonfly	Shia.1 Damselfly
TA	13.2	2.8	8.4	3.5	8.0	1.4	14.8	12.3
SEA	6.2	1.5	4.1	1.6	3.9	0.8	10.3	5.8
SEA <sub>C</sub>	7.0	1.6	4.6	1.8	4.2	0.9	11.8	6.6



## Appendix

**Diversity raw data.** Collected summer of 2016 for diversity and dispersal ability analysis for thesis.

Site	Type	Date	Season	PlantDiv	TDS	DO	WT	Wetted Fetch	Near_Shiawassee
Back Pool	Isolated	5/13/2016	Spring	None	NA	NA	NA	9.74	NA
Bayou Marsh	Connected	7/20/2016	Summer	Medium	0.324	6.82	26.165	298.64	1803.827475
Bayou North J	Diked	7/20/2016	Summer	Medium	0.265	0.725	20.42	64.47	1644.363961
Bayou North	Diked	5/10/2016	Spring	Low	NA	NA	NA	64.47	1551.198612
Bowl	Isolated	5/13/2016	Spring	None	NA	NA	NA	44.11	NA
Cass J	Connected	7/21/2016	Summer	Medium	0.425666667	6.52	23.5	288.62	438.2762518
Cass	Connected	5/12/2016	Spring	Medium	NA	NA	NA	288.62	438.2272801
Central Pool J	Diked	7/19/2016	Summer	Low	0.393333333	1.696666667	21.9	179.92	1781.315447
Central Pool	Diked	5/12/2016	Spring	Medium	NA	NA	NA	179.92	1793.041236
Eaglemarsh J	Connected	7/21/2016	Summer	High	0.443	1.406666667	23.38666667	249.1	382.0791055
Eaglemarsh	Connected	5/12/2016	Spring	Medium	NA	NA	NA	249.1	390.2631995
Eaglemarsh west	Connected	7/25/2016	Summer	Medium	0.315	0.735	24.705	69.3	219.7529544
Flint Swamp	Diked	5/11/2016	Spring	Low	NA	NA	NA	46.82	700.3609014
Front Pool J	Diked	7/26/2016	Summer	High	0.235	0.92	24.125	186.54	218.8737415
Grefe J	Diked	7/18/2016	Summer	Medium	0.446	1.76	23.42	672.21	1128.912371
Grefe	Diked	5/11/2016	Spring	Medium	NA	NA	NA	672.21	1065.848204
Landfill Pool	Isolated	5/13/2016	Spring	High	NA	NA	NA	8.84	NA
Old Wetland	Isolated	5/13/2016	Spring	High	NA	NA	NA	16.46	NA
Pool 1A J	Diked	7/18/2016	Summer	High	0.378	2.506666667	26.53	1038.51	75.27055485
Pool 1A	Diked	5/10/2016	Spring	Medium	NA	NA	NA	1038.51	370.6224837
Pool 1A south	Diked	7/25/2016	Summer	Medium	0.45	0.54	24.855	684.86	887.0121618
Pool 2A J	Diked	7/19/2016	Summer	High	0.3785	3.11	23.96	222.15	669.7931688
Pool 2A	Diked	5/10/2016	Spring	low	NA	NA	NA	222.15	186.0631178
Restoration Pool1	Isolated	5/13/2016	Spring	Medium	NA	NA	NA	13.11	NA
Restoration Pool2	Isolated	5/13/2016	Spring	Medium	NA	NA	NA	10.36	NA
Shiawassee 1 J	Connected	7/19/2016	Summer	High	0.4245	4.025	25.405	828.16	660.0179516
Shiawassee 1	Connected	5/11/2016	Spring	Medium	NA	NA	NA	828.16	118.9830235
Shiawassee 2	Connected	7/18/2016	Summer	Medium	0.543666667	4.85	25.74666667	1847.35	56.28308138
Shiawassee 3	Connected	7/21/2016	Summer	Medium	0.6	6.025	27.46	442.35	97.72884245
SPG J	Connected	7/18/2016	Summer	High	0.5665	2.66	23.365	47.81	1062.652671
SPG	Connected	5/9/2016	Spring	Medium	NA	NA	NA	47.81	1040.261899

Near_River	Near_meta1000	Dist_meta2500	Dist_meta5000	Channel_dist	Flooding_height	Depth	Area	Avecover	Abundance	Nochiron
142.03	258.72	258.72	258.72	142.03	2.1	0.500	0.0138	0.000	137	2
183.41	530.47	1416.33	2262.07	419.18	2.136	0.309	101.997	8.750	109	50.5
713.36	558.13	1361.75	2200.74	1184.28	1.949	0.364	12.089	11.250	69	42.5
553.94	546.27	1319.07	2155.33	818.00	3.402	0.289	12.089	5.000	90	87
139.59	273.85	273.85	273.85	139.59	2.3	0.100	0.159	0.000	89	12
26.88	451.62	1118.22	2466.69	65.71	0	0.500	5.223	5.000	167	157
26.92	451.76	1118.69	2467.31	66.19	0	0.275	5.223	20.000	163	164
1367.04	604.66	1477.40	2384.03	2018.29	5.082	0.701	35.525	15.000	113	102
1378.14	606.21	1486.91	2396.07	2013.94	5.082	0.150	35.525	42.500	160	138
36.29	394.54	1061.44	2409.02	115.28	0.51	0.313	14.223	11.667	254	236
45.38	398.67	1060.56	2405.96	92.66	0	0.350	14.223	25.000	118	106
219.75	686.63	1409.70	2166.69	206.69	0.717	0.478	38.034	16.250	155	147
78.72	576.70	1711.35	2933.46	489.97	3.112	0.500	1.841	3.750	125	55
218.87	478.43	1364.85	2093.19	396.87	2.138	0.630	7.737	85.000	89	77
161.02	535.94	1395.52	2082.40	748.84	1.105	0.370	64.149	15.000	47	47
90.85	671.13	1417.52	2023.55	829.34	1.105	0.500	64.149	23.750	166	105
61.87	236.13	236.13	236.13	61.87	5.5	0.300	0.009	10.000	87	33
9.14	173.84	173.84	173.84	9.14	1.1	0.200	0.053	3.000	132	28
75.27	729.33	1540.35	2158.20	610.26	1.698	0.387	128.034	21.000	84	63
370.62	569.74	1365.12	2049.18	141.59	2.29	0.388	128.034	52.500	63	63
771.12	700.10	1353.48	2018.04	414.64	3.26	0.330	128.034	82.500	99	99
661.88	515.83	1560.80	2610.44	303.60	1.075	0.851	46.47	23.750	112	109
54.60	511.01	1165.98	2783.71	960.38	1.0995	1.250	46.47	10.000	147	134
9.55	164.89	164.89	164.89	9.55	1.5	0.800	0.015	0.000	73	41
8.84	157.88	157.88	157.88	8.84	4.4	0.500	0.016	30.000	65	44
658.53	531.45	1569.29	2657.91	49.16	0	0.592	57.074	17.500	160	152
58.03	517.14	1088.45	2785.48	371.88	0	0.200	57.074	22.500	177	155
56.28	548.22	1405.92	2100.15	64.85	0	0.528	5.551	16.667	119	128
97.73	496.67	979.21	2337.12	134.02	0	0.378	1.912	11.250	119	122
44.61	685.37	1467.04	2054.01	66.01	0.255	0.200	1.513	47.500	68	63
46.76	683.77	1484.27	2045.99	54.10	0	0.500	1.513	43.750	117	95

Richness	Rare	ShanInd	Odonate	Damsel	Dragon	Beetle	Midge	Surface	Shells	EPT	Bug	Mite	Fly	Crab	SwimN	SwimW	SwimS
4	1	0.46	0	0	0	1	2	1	0	1	0	0	0	0	2	1	1
31	3	3.04	3	2	1	4	3	14	4	2	9	1	1	1	13	5	13
12	0	2.01	1	1	0	1	2	5	3	0	4	1	0	0	7	1	4
19	1	2.21	0	0	0	7	2	9	4	0	2	1	1	2	9	3	7
5	0	1.03	0	0	0	2	2	3	0	0	1	0	2	0	2	0	3
44	1	3.3	5	4	1	7	3	17	4	4	9	0	3	4	14	9	21
35	1	2.91	5	5	0	8	3	11	4	3	2	1	1	5	13	10	12
26	1	2.74	1	1	0	7	2	13	3	1	6	1	2	1	9	5	12
19	1	2.5	3	3	0	5	2	7	2	2	2	0	1	2	6	5	8
38	1	3.09	5	2	3	6	3	17	3	1	9	1	0	4	12	10	16
33	1	3.08	4	3	1	4	3	8	4	2	4	2	4	4	14	9	10
35	1	3.1	3	3	0	6	3	14	3	2	7	2	2	3	12	8	15
19	1	2.3	2	2	0	5	4	7	3	0	2	0	0	2	8	4	7
19	1	2.67	3	2	1	2	3	7	1	1	4	0	1	1	7	5	7
15	3	2.05	1	1	0	8	0	10	2	0	2	0	0	1	2	3	10
24	1	2.55	5	4	1	1	3	6	2	2	4	1	1	2	12	7	5
13	1	1.85	1	1	0	4	2	8	1	0	4	0	2	1	3	2	8
14	2	1.37	1	1	0	4	2	8	1	0	4	1	3	0	6	1	7
21	1	2.59	3	3	0	4	3	7	3	1	3	0	1	2	8	6	7
22	1	2.74	2	2	0	3	2	10	2	2	7	2	0	1	6	4	12
20	1	2.52	0	0	0	6	0	12	2	3	6	0	0	1	3	4	13
18	1	2.25	2	2	0	3	1	8	3	0	5	0	1	2	6	4	8
28	1	2.71	5	3	2	2	3	4	5	1	2	1	1	3	14	9	5
11	1	1.86	1	1	0	3	2	5	0	2	2	0	3	0	3	3	5
16	2	2.34	4	3	1	3	3	4	0	1	1	2	4	1	6	6	4
34	1	2.93	2	1	1	5	2	14	3	3	9	1	1	5	9	8	17
23	1	2.33	3	3	0	2	3	4	2	3	1	1	3	3	11	7	5
30	1	2.9	4	4	0	5	0	10	3	1	5	3	2	3	12	7	11
33	1	3.07	3	2	1	4	1	12	5	1	7	3	1	4	13	7	13
30	1	3.17	2	2	0	10	1	14	5	1	4	0	3	2	11	4	15
33	1	3.12	4	3	1	4	4	8	4	2	4	1	6	3	17	5	11

PerSwimS	FlyerN	FlyerW	FlyerS	PerFlyerS	Green	Red	White	Chrysomelidae	Curclionidae	Acilius	Agabus	Coptotomus	Desmopachria
25	0	3	1	25	0	0	0	0	0	0	0	0	0
42	8	12	11	35	0	0	2	0	2	0	0	0	4
33	4	5	3	25	0	20	0	0	0	0	0	0	0
37	7	4	8	42	0	0	1	0	0	2	0	1	15
60	0	2	3	60	0	0	0	0	0	0	0	0	2
48	10	20	14	32	0	0	0	0	0	0	0	1	0
34	12	12	11	31	6	0	0	0	1	0	0	3	0
46	5	10	11	42	0	18	0	0	0	0	0	7	1
42	4	9	6	32	0	0	0	0	0	0	0	0	7
42	10	12	16	42	0	1	0	0	0	0	0	1	0
30	11	13	9	27	7	2	0	0	0	0	0	0	0
43	10	14	11	31	1	16	0	0	0	0	0	2	2
37	6	7	6	32	0	0	0	0	0	5	0	2	2
37	3	9	7	37	0	0	0	0	0	0	0	0	0
67	4	2	9	60	0	0	0	0	0	0	1	3	5
21	7	12	5	21	0	5	0	0	0	0	0	0	0
62	2	5	6	46	0	0	0	0	0	0	0	0	1
50	2	5	7	50	0	4	0	0	0	0	0	0	1
33	5	9	7	33	0	0	0	0	0	0	0	4	0
55	6	8	8	36	10	1	0	0	0	0	0	0	2
65	4	4	12	60	0	0	0	0	0	0	0	5	0
44	6	5	7	39	0	0	0	0	0	0	0	0	0
18	10	12	6	21	3	0	0	0	0	0	0	5	0
45	0	6	5	45	0	0	0	0	0	0	0	0	5
25	3	8	5	31	1	1	0	0	0	0	0	0	2
50	10	10	14	41	0	4	0	0	0	0	0	0	2
22	7	12	4	17	2	0	0	0	0	0	0	0	0
37	10	9	11	37	1	2	3	2	1	0	0	0	0
39	14	7	12	36	1	1	2	0	0	0	0	2	0
50	7	10	13	43	0	0	0	0	0	1	0	1	2
33	8	13	12	36	0	1	0	0	0	1	0	3	0

Dytiscus	Hydrotrupes	Laccophilus	Matus	Macronychus	Dineutus	Gyretes	Gyrinus	Haliphus	Peltodytes	Hydraena	Hydrocus	Berosus
0	0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	3	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	4	2	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	4	2	0	0	0	4
0	0	1	1	0	1	0	0	1	0	0	0	1
0	0	0	0	0	8	0	0	0	1	0	4	0
11	0	1	0	0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	2	0	1	1	0	0	0
1	0	0	0	0	0	0	1	0	3	0	0	1
0	0	0	4	0	0	0	0	1	2	0	0	0
0	0	0	0	0	0	0	2	2	0	0	0	0
0	0	0	0	0	0	0	0	3	0	0	0	0
1	1	1	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	4	0	0	0
0	7	1	0	0	0	0	0	0	3	0	0	0
8	0	0	0	0	2	0	0	0	0	0	0	2
0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	4	0	0	1
0	0	0	3	0	0	0	0	0	4	0	0	0
0	0	0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	1	0	0	3	1	0	0	0
0	0	0	0	0	0	0	0	0	3	0	0	1
0	0	0	3	0	0	0	0	0	0	1	0	0
0	0	0	1	0	0	0	0	4	0	0	0	0
0	6	2	0	2	0	0	0	2	0	0	0	2
0	0	0	0	0	0	0	0	0	0	0	0	5

Dibolocelus	Hydrobius	Hydrochara	Tropisternus	Gammarus	Hyaella	Copopoda	Asselus	Decapoda	Bezzia	Culicoides	Stilobezzia	Chaoborus
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	2	0	6	0	0	0	2	0	0	0
0	0	0	3	0	0	0	0	0	0	0	0	0
1	0	0	0	0	6	0	1	0	3	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	3	9	26	0	5	2	1	0	0	0
0	0	0	2	15	33	2	14	3	2	0	0	0
3	0	0	2	0	11	0	0	0	0	0	0	1
1	0	0	0	0	22	0	2	0	14	0	0	0
3	0	0	5	1	40	7	13	0	0	0	0	0
0	0	0	0	3	7	0	17	3	7	0	0	0
1	0	0	0	0	24	17	0	1	1	0	0	0
0	0	0	0	2	0	0	6	0	0	0	0	0
1	0	0	0	0	17	0	0	0	4	0	0	0
0	0	2	0	0	22	0	0	0	0	0	0	0
0	0	0	0	0	3	0	2	0	2	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	2	2	18	0	0	0	1	0	0	0
1	0	0	2	0	7	0	0	0	0	0	0	0
0	0	2	3	0	28	0	0	0	0	0	0	0
0	0	0	1	0	37	0	16	0	1	0	0	0
0	0	0	0	1	25	0	11	0	3	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	1	0	0	1	0	0	0	7	0	0	0
0	0	0	1	18	14	1	11	1	0	0	0	0
0	0	0	0	33	0	0	32	1	2	0	2	0
0	1	0	0	8	13	0	26	0	1	0	0	0
1	0	0	0	16	14	1	10	0	0	0	0	0
0	0	1	1	0	5	0	3	0	0	0	0	0
1	0	0	0	0	4	0	9	5	1	2	0	0

Eucoethra	Chironominae	Chironomini	Orthocladiinae	Tanypodinae	Tanytarsini	Aedes	Anopheles	Rhaphium	Megaselia	Caloparyphus	Stratiomys
0	118	17	0	0	0	0	0	0	0	0	0
0	8	1	0	3	0	0	0	0	0	0	0
0	0	0	0	1	3	0	0	0	0	0	0
0	1	0	0	3	0	0	0	0	0	0	0
0	24	53	0	0	0	0	0	0	0	0	0
0	6	1	0	1	0	0	2	0	0	1	0
0	2	1	0	0	3	0	0	0	0	0	0
0	27	0	0	2	0	0	0	0	0	0	0
0	15	7	0	0	0	0	0	0	0	0	0
0	7	0	4	8	0	0	0	0	0	0	0
0	8	10	0	3	0	0	0	1	0	0	0
0	10	0	8	4	0	0	3	0	0	0	0
0	6	0	20	43	1	0	0	0	0	0	0
0	1	4	0	7	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	24	3	0	39	0	0	0	0	0	0	0
0	37	17	0	0	0	0	0	0	0	0	0
0	23	85	0	0	0	0	0	0	2	0	0
0	1	4	0	16	0	0	0	0	0	0	0
0	3	0	0	8	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	3	0	0	0	0	0	0	0	0	0	0
0	12	0	0	3	1	0	0	0	0	0	0
0	7	25	0	0	0	0	0	0	0	0	0
0	8	11	0	4	0	0	0	0	0	0	0
0	9	0	3	0	0	0	0	0	0	0	1
3	9	13	0	2	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	1	0	0	0	0	0	0	0	1
1	1	0	0	0	0	2	0	0	0	0	0
0	0	7	3	10	2	0	1	0	0	1	0

Chrysops	Silvius	Tabanus	Tanyderus	Tipula	Ameletus	Baetis	Baetisca	Proclleon	Caenis	Isonychia	Leptophlebia	Anthopotamus	Ancylidae
0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	2	8	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	5	6	0	0	1	0
0	0	0	0	0	0	0	1	0	23	1	0	0	0
0	0	0	2	0	0	0	0	0	7	0	0	0	0
0	0	0	0	0	0	0	0	2	2	0	0	0	0
0	0	0	0	0	0	0	0	0	14	0	0	0	0
1	0	0	0	1	0	0	0	7	6	0	0	0	0
0	0	0	0	0	0	0	0	3	4	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	9	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	6	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	1	10	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	7	0	0	0	1
0	0	0	0	0	0	0	0	7	0	0	2	0	0
0	0	0	0	0	0	0	0	3	0	0	0	0	0
0	0	0	0	0	0	0	0	1	3	0	0	0	0
0	0	0	0	0	1	0	0	0	6	0	1	0	0
0	0	0	0	0	0	0	0	0	9	0	0	0	0
0	0	0	0	0	0	0	0	0	11	0	0	0	0
0	0	0	0	1	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	0	0	0	0



Hydrobiidae	Lymnaea	Planorbidae	Physa	Musculium	Belostoma	Callicorixa	Corisella	Hespercorixa	Neocorixa	Ramphocorixa	Trichocorixa	Aquarius
0	0	0	0	0	0	0	0	0	0	0	0	0
0	2	4	3	1	7	1	3	0	1	0	0	1
0	11	6	0	12	6	0	1	0	0	0	0	0
0	5	2	7	1	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	9	0	0	0	0	0
0	1	4	8	2	2	0	2	0	0	0	0	1
0	3	4	2	12	8	0	1	0	0	0	0	0
0	1	9	1	0	7	0	1	0	0	0	0	0
0	0	1	24	0	1	0	0	0	0	0	0	0
0	7	17	8	0	20	0	6	0	0	0	5	0
0	2	1	15	3	0	0	0	1	0	0	0	0
0	2	4	2	0	14	0	6	0	0	0	0	1
0	6	0	8	3	0	0	0	0	0	0	0	0
0	0	0	7	0	5	0	0	0	0	0	0	0
0	0	3	1	0	1	0	0	0	0	0	0	0
0	0	0	2	4	0	0	15	0	0	0	0	0
0	0	0	6	0	0	0	7	0	0	0	0	1
0	0	0	1	0	0	0	1	0	0	0	0	0
0	1	0	5	1	3	0	0	0	0	0	0	0
0	0	2	1	0	11	0	2	0	0	0	2	0
0	1	7	0	0	10	0	6	0	7	0	0	1
0	0	1	4	5	4	0	3	0	0	0	2	0
0	1	1	1	4	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	5	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	8	4	9	0	31	0	0	0	15	1
0	6	0	48	0	0	0	0	0	4	0	0	0
0	0	7	7	2	6	0	1	0	0	0	2	0
2	3	3	4	1	8	0	4	0	0	1	3	1
1	5	1	5	3	7	0	3	0	0	0	0	1
0	11	2	10	10	0	1	3	0	0	0	0	0

Gerris	Neogerris	Metrobates	Trepobates	Ranatra	Notonecta	Neoplea	Paraplea	Microvelia	Ichneumonidae	Hydrudinea	Elophila	Synclita	Anax	Coenagrion
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	5	23	0	6	0	1	0	0	0	0
0	0	0	0	1	0	24	0	0	0	0	0	0	0	0
0	0	0	0	0	0	34	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	0	0	1	10	7	2	0	6	1	0	1	9
0	0	0	0	0	0	0	0	0	0	5	0	0	1	1
0	0	0	2	1	6	0	5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	18	0	0	0	0	0	0	1
0	1	0	0	2	6	13	2	2	1	25	0	3	4	1
1	0	0	0	0	3	0	3	0	0	1	0	0	0	1
0	0	0	0	1	6	7	0	2	0	2	0	0	7	1
0	0	0	0	0	1	5	0	0	0	1	0	0	0	0
0	0	0	0	0	2	3	0	3	0	0	0	0	4	0
0	0	0	0	0	0	3	0	0	0	1	0	0	0	0
0	0	0	0	1	3	0	31	0	0	1	0	0	0	4
0	0	0	0	0	2	0	0	2	0	0	0	0	0	0
1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	1	4	0	0	0	0	0	0	0	1	5
0	1	0	0	0	5	2	1	0	0	8	0	0	0	0
0	0	0	0	2	5	0	0	0	0	2	0	0	3	0
0	0	0	0	0	4	18	0	0	0	2	0	0	0	0
0	0	0	0	0	0	0	30	0	0	1	0	0	0	5
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	2	1	2	3	0	1	0	3	0	0	4	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1	0	0	0	0	0	4	0	0	0	4	1	0	1	4
0	0	0	0	0	0	4	0	1	0	7	0	0	2	2
0	0	0	0	0	0	0	0	1	0	0	0	0	2	1
1	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Enalleg.	Ischnura	Nehalen.	Cordulia	Epitheca	Somatochl.	Archil.	Lestes	Eryth.	Libel.	Oligo.	Sald.	Oecetis	Leptoc.	Triaen.	Cerno.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	3	0	3	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10	1	0	0	0	0	0	1	0	2	0	0	0	0	0
4	7	2	0	0	0	1	0	0	0	2	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
10	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	17	0	1	0	2	0	0	2	0	1	1	0	0	0	0
0	1	0	0	0	1	3	0	0	0	0	0	2	0	0	0
4	7	0	0	0	0	0	0	0	0	1	1	0	0	0	0
1	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
3	3	0	0	0	0	0	0	1	0	2	10	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	5	0	0	0	0	0	2	0	9	1	0	0	2	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	14	0	0	1	0	0	0	0	2	0	0	1	4	0	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	3	0	0	0	1	4	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
5	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0
10	4	1	0	0	0	0	0	0	0	0	1	0	0	0	0
3	0	0	0	0	0	0	0	1	0	6	1	0	0	0	0
0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	1	12	3	0	0	0	0	0	0	4	0

**Stable Isotope raw data.** Collected summer of 2016 for food web analysis.

Sample	Site	Type	Diversity	Order	Genus	Corrected d13C	Corrected d15N	C/N	Weight
AA2R1.raw	Pool 2A	Diked	Medium	Amphipoda	Amphipod	-22.07	3.68	4.84	15
AA2M1A.raw	Pool 2A	Diked	Medium	Amphipoda	Amphipod	-22.4	4.93	4.86	15
AA2M1B.raw	Pool 2A	Diked	Medium	Amphipoda	Amphipod	-21.89	4.38	4.81	15
AA2M1C.raw	Pool 2A	Diked	Medium	Amphipoda	Amphipod	-22.97	4.85	4.88	15
AASM1.raw	Shiawassee 1	Connected	High	Amphipoda	Amphipod	-24.28	5.99	5.07	20.04
AASM2A.raw	Shiawassee 1	Connected	High	Amphipoda	Amphipod	-24.7	6.57	4.85	20.8
AAEM1A.raw	Eaglemarsh	Connected	High	Amphipoda	Amphipod	-23.11	12.57	4.91	28.02
AAEM1B.raw	Eaglemarsh	Connected	High	Amphipoda	Amphipod	-23.26	12.75	4.87	13.95
AAEM1C.raw	Eaglemarsh	Connected	High	Amphipoda	Amphipod	-23.1	12.68	4.89	14.92
AAEM1D.raw	Eaglemarsh	Connected	High	Amphipoda	Amphipod	-23.48	12.72	4.84	9.65
AAEM1E.raw	Eaglemarsh	Connected	High	Amphipoda	Amphipod	-23.41	12.95	4.81	13.7
AAEM1F.raw	Eaglemarsh	Connected	High	Amphipoda	Amphipod	-23.32	13.07	4.82	9.19
AAWM1A.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-20.5567	5.990027	4.745918	7.89
AAWM2C.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-22.2673	5.147746	4.89739	12.92
AAWM2A.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-21.6827	4.811803	5.01419	8.87
AAWM2B.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-22.4232	4.758949	4.805581	10.63
AAWM2D.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-21.9816	4.915209	4.800508	12.24
AAWM2E.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-22.1891	4.87084	4.930484	5.87
AAWM3.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-22.1189	5.582244	4.799404	4.42
AAWM1B.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-20.1994	5.343049	4.931312	6.11
AAWM1C.raw	Shiawassee 2	Connected	Medium	Amphipoda	Amphipod	-21.0816	5.970379	4.820938	5.65
AA1M1A.raw	Pool 1A	Diked	Low	Amphipoda	Amphipod	-23.9257	3.724214	4.732184	4.37
AA1M1B.raw	Pool 1A	Diked	Low	Amphipoda	Amphipod	-24.0376	3.999271	4.81724	8.17
AA1M1C.raw	Pool 1A	Diked	Low	Amphipoda	Amphipod	-24.3065	3.456086	4.756477	3.94
AA1M1D.raw	Pool 1A	Diked	Low	Amphipoda	Amphipod	-24.32	3.477577	5.000129	5.96
AA1R1A.raw	Pool 1A	Diked	Low	Amphipoda	Amphipod	-24.6208	8.117901	4.905113	2.96
AA1R1B.raw	Pool 1A	Diked	Low	Amphipoda	Amphipod	-23.0701	8.0155	4.773328	6.84

AJ2M1.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-23.45	6.15	4.05	131.15
AJ2M2.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-24.66	6.78	3.97	18.25
AJ2M3.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-21.74	6.12	4.03	217.61
AJ2M4.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-23.97	5.96	4.21	87.73
AJ2M5.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-24.78	6.78	4.13	53.5
AJ2M6.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-24.8	6.48	4.34	326.45
AJ2M7.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-22.15	6.14	4.02	49.52
AJ2M8.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-22.88	6.16	4.27	253.04
AJ2M9.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-26.61	6.22	3.96	49.84
AJ2M10.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-23.45	4.69	4.04	28.81
AJ2M11.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-21.93	4.82	4.06	17.94
AJ2M13.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-28.14	6.43	4.2	61.4
AJ2M14.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-28.27	6.51	4	44.51
AJ2M15A.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-27.42	6.09	4.13	9.16
AJ2M15B.raw	Pool 2A	Diked	Medium	Anisoptera	Anax	-22.96	6.53	4.04	45.04
AJSM1.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-26.31	6.67	4.25	59.76
AJSM2.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-26.83	8.39	3.88	54.87
AJSM3.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-22.2	9.47	4.2	23.29
AJSM4.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-22.45	8.08	4.39	62.2
AJSM5.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-26.77	7.05	4.4	83.41
AJSM6.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-28.03	7.15	4.12	15.54
AJSM7.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-25.53	6.96	4.27	60.17
AJSM8.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-21.94	5.62	4.3	54.65
AJSM9A.raw	Shiawassee 1	Connected	High	Anisoptera	Anax	-21.78	5.31	4.16	22.17
AJEM1.raw	Eaglemarsh	Connected	High	Anisoptera	Anax	-29.54	12.9	4.32	227.17
AJEM2.raw	Eaglemarsh	Connected	High	Anisoptera	Anax	-26.06	13.25	4.39	118.4
AJEW1.raw	Eaglemarsh	Connected	High	Anisoptera	Anax	-28.53	13.39	4.23	62.41
AJFM1.raw	Flint	Diked	Low	Anisoptera	Anax	-27.17	4.7	4.35	113.86
AJFM2A.raw	Flint	Diked	Low	Anisoptera	Anax	-23.11	6.09	4.18	19.83
AJFM2B.raw	Flint	Diked	Low	Anisoptera	Anax	-27.77	4.09	4.21	14.43

<b>AJFM3.raw</b>	Flint	Diked	Low	Anisoptera	Anax	-22.4	6	4.26	119.87
<b>AJWR1Bb.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-26.4303	6.64473	4.215289	56.12
<b>AJWR2Ab.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-22.8906	6.998753	3.94407	3.95
<b>AJ1M1A.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-27.8351	3.787784	4.375087	45.98
<b>AJ1M1B.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-27.6882	4.327957	4.202714	7.75
<b>AJ1M1C.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-23.2986	5.880936	4.17762	9.24
<b>AJ1M2.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-28.1808	4.06159	4.44371	65.05
<b>AJ1M3A.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-29.2153	5.258421	4.18665	18.84
<b>AJ1M3B.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-26.2463	4.312475	4.312306	12.5
<b>AJ1M4.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-28.0501	3.682418	4.432944	61.04
<b>AJ1M5A.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-27.8361	3.89401	4.348436	45.01
<b>AJ1M5B.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-27.0499	4.051044	4.476527	39.93
<b>AJ1R1.raw</b>	Pool 1A	Diked	Low	Anisoptera	Anax	-24.581	8.342725	4.43779	103.47
<b>AJWM2B.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-22.6921	5.874135	4.25871	15.84
<b>AJWM2C.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-22.8372	6.15864	4.085279	22.57
<b>AJWR1A.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-22.6939	6.824451	4.086952	6.05
<b>AJWM1B.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-21.6664	5.941451	4.158581	15.54
<b>AJWM3B.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-26.269	6.316652	4.30773	44.43
<b>AJWM1A.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-19.8862	5.613135	4.042036	12.25
<b>AJWR2B.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-22.5236	7.390195	4.29756	44.24
<b>AJWM2Ab.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-22.4021	5.954142	3.91283	19.83
<b>AJWM3Ab.raw</b>	Shiawassee 2	Connected	Medium	Anisoptera	Anax	-27.0178	7.973859	4.359856	39.67
<b>IP2M1.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Ischnura	-28.03	6.65	4.1	18.47
<b>IP2M2.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Ischnura	-28.82	6.78	3.97	17.54
<b>IP2M3.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Ischnura	-27.11	6.33	3.9	16.27
<b>EC2M1A.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-26.14	6.09	4.19	13.15
<b>EC2M1B.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-27.17	6.39	4.07	11.85
<b>EC2M1C.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-25.89	6.29	4.13	10.51
<b>EC2M2A.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-27.29	6.86	4.03	14.15
<b>EC2M2B.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-28.33	7.03	4.05	13.07

<b>EC2M2C.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-25.45	6.24	4.08	18.44
<b>EC2R1.raw</b>	Pool 2A	Diked	Medium	Zygoptera	Enallagma	-24.6	6.07	4.08	5.68
<b>IPSM1.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Ischnura	-25.74	9.07	4.16	13.51
<b>IPSM2.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Ischnura	-24.77	7.06	4.16	7.98
<b>IVSM1.dw.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Ischnura	-19.69	8.79	4.25	12.02
<b>IVSM2.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Ischnura	-26.22	7.75	4.15	20.16
<b>IVSM3.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Ischnura	-22.29	6.67	4.19	9.25
<b>ECSM1A.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Enallagma	-24.28	6.41	4.22	10.13
<b>ECSM1B.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Enallagma	-24.01	7.71	4.17	16.08
<b>ECSM2A.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Enallagma	-23.18	9.32	4.2	10.15
<b>ECSM2B.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Enallagma	-23.35	7.03	4.09	9.1
<b>ECSM2C.raw</b>	Shiawassee 1	Connected	High	Zygoptera	Enallagma	-23.34	7.91	4.19	11.13
<b>IVER1.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-28.01	14.35	4.13	11.28
<b>IVEM1A.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-27.98	14.25	4.11	11.04
<b>IVEM1B.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-26.75	14.24	4.22	10.41
<b>IVEM1C.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-26.5	14.16	4.24	12.42
<b>IVEM1D.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-28.15	14.12	4.17	10.03
<b>IPEM1A.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-27.79	14.25	4.2	11.34
<b>IPEM1B.raw</b>	Eaglemarsh	Connected	High	Zygoptera	Ischnura	-27.38	14.36	4.24	11.02
<b>ECFM1A.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-21.13	6.58	4.27	7.15
<b>ECFM1B.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-22.75	6.04	4.21	8.19
<b>ECFM2A.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-23.42	6.28	4.14	10.73
<b>ECFM2B.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-23.43	5.89	4.01	8.69
<b>ECFM2C.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-23.06	5.81	4.17	7.23
<b>ECFM2D.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-22.84	5.15	4.07	4.14
<b>ECFM3.raw</b>	Flint	Diked	Low	Zygoptera	Enallagma	-22.83	6.83	4.1	9.36
<b>IPFM1.raw</b>	Flint	Diked	Low	Zygoptera	Ischnura	-22.92	6.12	4	11.03
<b>IPFM2A.raw</b>	Flint	Diked	Low	Zygoptera	Ischnura	-22.4	5.13	4.17	8.08
<b>IPFM2B.raw</b>	Flint	Diked	Low	Zygoptera	Ischnura	-22.06	6.64	4.13	13.21
<b>IPFM3.raw</b>	Flint	Diked	Low	Zygoptera	Ischnura	-22.33	7.14	4.11	9.95

<b>IVIW1A.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.1134	7.668428	4.170166	9.19
<b>IVIW1B.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.8759	7.336721	4.374203	10.85
<b>IP1M1A.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-28.0903	5.119636	4.210911	6.76
<b>IP1M1B.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.3238	4.940207	4.156349	4.17
<b>IP1M1C.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.3237	4.995407	4.150555	4.63
<b>EC1R1.raw</b>	Pool 1A	Diked	Low	Zygoptera	Enallagma	-27.4326	8.301943	4.268575	8.39
<b>EC1R2.raw</b>	Pool 1A	Diked	Low	Zygoptera	Enallagma	-27.4069	6.591419	4.227937	8.66
<b>IV1M1A.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.454	3.600874	4.425394	9.52
<b>IV1M1B.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.4187	4.957083	4.219556	6.17
<b>IP1R1.raw</b>	Pool 1A	Diked	Low	Zygoptera	Ischnura	-27.6679	8.422504	4.273904	10.95
<b>ECWR1A.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Enallagma	-23.9622	7.29551	4.180695	6.65
<b>ECWM1A.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Enallagma	-20.693	6.757521	4.201402	6.26
<b>ECWR1B.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Enallagma	-20.9047	6.074455	4.064416	5.58
<b>ECWM1B.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Enallagma	-21.2886	6.438862	4.126136	5.68
<b>IPWM1A.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-21.6197	6.391471	4.071352	5.18
<b>ECWM1C.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Enallagma	-20.6603	5.331767	4.060286	3.09
<b>ECWR1C.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Enallagma	-23.3998	7.268316	3.954204	3.82
<b>IVWM1B.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-22.2592	6.483534	4.133767	5.35
<b>IVWM2A.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-21.9681	6.129851	4.117795	7.57
<b>IPWR1.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-22.1163	7.102326	4.145073	10.95
<b>IVWM2B.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-19.5209	5.295352	4.170518	7.75
<b>IPWM1B.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-20.712	6.277955	4.053457	4.42
<b>IVWM2C.raw</b>	Shiawassee 2	Connected	Medium	Zygoptera	Ischnura	-20.2746	5.12642	4.222178	12.57
<b>CR1M1.raw</b>	Pool 1A	Diked	Low	Zygoptera	Coenagrion	-27.3972	4.614489	4.11703	11.67
<b>CR1R1.raw</b>	Pool 1A	Diked	Low	Zygoptera	Coenagrion	-27.1325	7.67933	4.046332	4.85



## Glossary

Channel distance: the shortest distance measured from a source habitat (river) to a sink habitat (floodplain wetland) which travels along the natural flow of water.

Connected: study sites that are naturally occurring floodplain wetlands without any manmade structure.

Dike: a manmade earthen structure used to separate areas of land. Typically used to manage wetlands.

Dispersal ability: the relative ability of an organisms to traverse through space and time.

Flooding height: the height of obstruction, manmade or natural, that prevents water from flowing between habitat patches. Measured from the surface water elevation to the lowest elevation (water controlling point) of the obstruction. Correlated with flooding frequency.

Isolated: study sites located exclusively at the Brent Run study area which were vernal pools associated with the river, but formed by rain water.

Levee: a manmade structure placed along a river to prevent flooding.

Non-flyer: an organisms that doesn't not have the ability to fly at any life stage (e.g. crustaceans).

Non-swimmer: an organism that is not capable of traveling through the water column by its own means (e.g. mollusk).

Strong flyer: an organism that is capable of traveling long distances and is not impacted as much by the wind (e.g. dragonfly).

Strong swimmer: an organism that easily traverses the water column and can move against slow flowing water (e.g. adult beetles)

Weak flyer: an organism that can only traverse small distances before stopping and or an organisms that is dispersed by the wind (e.g. midges).

Weak swimmer: an organism that can swim, but moves more passively through the water column (e.g. midges).