UNIVERSITY OF NOTRE DAME RESEARCH CENTER

Land O' Lakes, WI

Stream Scare: Riparian Species Richness and Fish Diversity as Indicators of Stream Health

Tara Hill

Saint Mary's College
Notre Dame, IN
thill01@saintmarys.edu

Advisor: Dr. Todd Crowl

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Abstract

Stream health is a major concern for communities that utilize its resources for freshwater or recreational activities, and for a diverse range of wildlife and vegetation. The distribution and diversity of fish and aquatic plants within freshwater streams can act as indicators of lotic ecosystem health. This study looks at two separate stream ecosystems within the same drainage basin. Kickapoo Stream is a small, slow moving headwater stream with minimal coverage. Here, riparian species richness and percent coverage of submergent, emergent, and floating vegetation was observed at various 27 distances flowing out of Kickapoo Lake (Figure 3). The West Branch Ontonagon River was the second study site. Here, fish diversity was sampled at four sites of varying distance from its main source (Cisco Lake; Figure 4). Riffle, run, and pool habitat type was sampled at each site. Length and mass of Redtail Chub, an abundant species of the West Branch Ontonagon River, was also taken at habitat type within each site. In Kickapoo, riparian species richness increased with increasing distance from Kickapoo Lake, but the percent coverage of vegetation was not affected with changes in distance. In the West Branch Ontonagon River, fish species richness and diversity did not differ with site (distance from mainsource lake) or habitat type (riffle, pool, or run). However, Redtail Chub mass and length differed with both site and habitat.

Introduction

Freshwater streams are important for various reasons ranging from a hometown communities' drinking water and recreational getaway to a habitat for diverse fish and wildlife. Maintaining stream health is essential in providing a sustainable ecosystem to provide these resources. Both fish diversity and riparian species richness can be important metrics of stream health. There are often similar responses to stream condition across trophic levels (Mazeika *et al.,* 2008), and insight into these responses can give researchers key information into the effects of human influences (Mazeika *et al.,* 2008) and natural disturbances (Montgomery, 1999) on stream ecosystems. Vannote *et al.* (1980) developed a frequently used framework to describe the structure and function of communities along healthy river systems known as the "River Continuum Concept" or the RCC (Figure 1). This framework looks at how the gradient of physical factors within drainage networks affects living organisms in fresh running water. Since the RCC does not take into account human influences (Mazeika *et al*., 2008; Merona *et al.*, 2005) or natural disturbances (Montgomery, 1999), it can act as a comparison tool to describe how disturbances lead way to various biological responses.

Small streams (orders 1-3) are greatly influenced by riparian vegetation (Vannote *et al.*, 1980). Since smaller streams have a small width, vegetation provides shade to a major part of the stream's surface area. This vegetative shading causes a reduction in autotrophic production and an increased amount of allochthonous detritus, which generally acts as the major nutrient source of headwater streams (Vannote *et al.*, 1980). Most studies on first order streams in North America take place in eastern deciduous forests; data is often focused on densely shaded areas (Ward & Stanford, 1983). However, not all headwater streams undergo heavy shading (Minshall, 1978). This study examined the riparian vegetation of Kickapoo stream, a first order stream in an open grassland habitat located in Michigan's Upper Peninsula.

Westlake (1975) recognized four major forms of riparian vegetation: (1) emergents occurring on river banks and shoals, (2) floating-leaved taxa rooted in submerged soils, (3) free-floating plants not attached to substrate, and (4) entirely submerged taxa attached to substrate. For this study I combined the two floating vegetation groups into one main major form of riparian vegetation. Observing the differences in coverage of these groups with increasing distance from the main source of first order streams allows insight into stream health when compared to the RCC (Figure 1).

The distribution of individual species and taxa can also be used to describe the trophic level structure as an indicator of stream health (Karr, 1999). Observations of a stream's intricate food web can show patterns of change stemming from disturbances of spatial/temporal changes. High quality streams have heterogeneous habitats, which can provide resources for an array of riparian vegetation, invertebrates, and fish (Allan, 1995). These habitats generally have high nutrient availability (Karr, 1999) and high oxygen content (Albanese *et al.*, 2004). Because they act as top level species within stream trophic structures, researchers can evaluate ecosystem health by fish distributions. An understanding of the distribution can illustrate patterns of fish assemblage structuring within streams (Fischer & Paukert, 2009) as well as giving insight into fish behavior based on predation, life stages, or physical environment.

Distance to or away from a drainage basin is an important factor that affects fish distribution and assemblage within an individual stream. This inclination is because habitat heterogeneity differs as streams branch from their main source. There is often more surface area and depth near a stream source, offering a larger habitat. However, faster moving waters with higher oxygen content (Albanese *et al.*, 2004) are generally more abundant further from a stream source. These fast moving waters are known as riffles, while more stagnant waters are known as pools. Riffles and pools are usually separated by runs, or areas of moderately flowing water between the two habitats. Many species are found mainly in riffles or pools, but seldom can they survive in both (Allan 1995).

Lower fish diversity closer to basins could be due to fish fitness on both a species and individual level. Larger fish might be able to travel greater distances away from their headwater streams, whereas smaller fish would likely remain further upstream. It is important to observe fish size within each species. Young fish, or fish with a lower fitness level that are smaller in size might reside in a given habitat because they are physically unable to travel from a certain area or are not yet in a life stage that would require the change in habitat.

Life history stages are an important factor that can affect fish distribution and abundance in streams. Migration patterns depend on different life history stages (Albanese *et al.*, 2004). The interaction of life histories and habitat requirements may explain why individuals of the same species reside in different habitats, such as in a riffle or pool. Habitat complexity provides fish an opportunity to save on the energy costs of migrating long distances with the ability to find a suitable habitat in all stages of life. This is another vital reason to maintain stream health and the ability for fish to maintain appropriate migratory patterns.

Habitat complexity also shows a positive correlation with the number of fish species found in a given area. The probability of fish movement often decreases with increasing habitat complexity (Albanese *et al.*, 2004), which could be due to the various forms of species' resources within a small space. A complex habitat can be defined as a habitat that contains runs, deep pools, and an abundance of cover (Albanese *et al.*, 2004). However, this can fluctuate with environmental conditions. For example, during the summer months riffles are often in higher demand with the decrease in oxygen solubility caused by the temperature increase (Allan, 1995). Albanese *et al.* (2004) found that higher species emigration and a higher mortality rate occur in stagnant pools because of the harsh environment found with the lack of oxygen, especially during the warm months of summer. In addition, Liefferinge *et al.* (2010) found that fish congregate in areas further away from large drainage sites or sources, due to the higher oxygen content in riffles that are found further upstream in shallower waters.

Though they might be oxygen stressed, sites closest to a lake can offer greater opportunity for habitat complexity with the larger amount of water space. Sample sites near drainage basins or lakes might also offer deeper waters that provide protection from predators

(Merona *et al.*, 2005). Though this is true from the predation of terrestrial animals, deeper waters are often prone to a higher predation threat from other fishes. Prey species often move into shallower waters with complex habitats to avoid this threat (Jackson *et al.*, 2001). Riffles offer little habitat space for larger top predators within stream trophic levels.

Kickapoo Stream and the West Branch Ontonagon River are both within the Ontonagon River drainage basin. Their water quality has a direct affect on Lake Superior, where both of their waters eventually flow. Studies on individual streams within the same drainage basin can offer insight into the health of entire watersheds. Since fish diversity and habitat diversity have a positive correlation (Liefferinge *et al.*, 2010), this study was broken into two segments: 1.) a survey of the riparian vegetation of Kickapoo Stream and 2.) a survey of fish diversity with increasing distance from a mainsource lake.

The questions of the riparian study on Kickapoo were: 1.) does riparian species richness differ with increasing distance from Kickapoo Lake (mainsource)? and 2.) does coverage of emergent, submergent, and floating vegetation differ with increasing distance from Kickapoo Lake? My hypotheses for this section were as follows: 1.) riparian species richness would remain constant with increasing distance from Kickapoo Lake, 2.) the percent coverage of floating and submergent vegetation would increase with increasing distance, and 3.) the percent coverage of emergent vegetation would decrease. These were based on the RCC's description of riparian vegetation on riverbanks being greatest at the beginning of first order streams (Figure 1). Because of this density, shading occurs that would prevent the growth of plants within the water because of a lack of sunlight availability. However, with increasing distance and decreasing emergent density, sunlight availability would increase, allowing more aquatic growth.

The questions of the study on fish diversity within the West Branch Ontonogan River were: 1.) do fish of the same species differ in size with increasing distance from a mainsource? and 2.) does fish diversity differ with increasing distance from a mainsource? My first hypothesis was that smaller bodied fish within each species would be found close to Cisco Lake (mainsource). This hypothesis was based on fish in earlier life stages (smaller bodied) not taking part in later migration movements (Albanese *et al.*, 2004). It was also based on larger fish having a higher fitness level (Albanese *et al.*, 2004), and the ability to move further up the north flowing stream. Our second hypothesis was that higher fish diversity would be observed in an increasing linear fashion as distance from Cisco Lake increased. This hypothesis was based on the higher availability of riffles further away from Cisco Lake (Albanese *et al.*, 2004), and therefore greater chances for a heterogeneous environment. The availability of riffles would be especially important for species in this study because it was conducted in July, when oxygen solubility levels would be lower (Allan, 1995).

Materials and Methods

Study Site

This study took place at two separate sites. Riparian surveying was conducted on a stream connecting Kickapoo and Brown Lakes located on the University of Notre Dame's Environmental Research Center, bordering Wisconsin and Michigan's Upper Peninsula (46°13' N, 89°32' W). This narrow stream, slow moving stream is part of the Ontonagon River drainage basin and has a high macrophyte abundance. Kickapoo Stream is in a grassland habitat, with little to no shading from emergent vegetation. The stream flows from Kickapoo Lake (1st order) a distance of 1664 meters until it meets Brown Creek. When Kickapoo Stream mixes with Brown Creek, it continues flowing as a 2nd order stream until it reaches Brown Lake. In total, the stream's distance from Kickapoo Lake to Brown Lake is 2292 meters. Human interactions on site are minimal. Therefore, the affect of human disturbances on stream ecosystems and individual trophic levels within streams (Mazeika *et al.*, 2008) is also minimal.

Fish diversity was taken on the West Branch Ontonagon River, flowing from Cisco Lake on Ottawa National Forest, MI (46°24'N, 89°44'W). This river is also within the Ontonagon River drainage basin and has a diversity of riffle, pool, and run environments. As part of the Ottawa National Forest, the West Branch Ontonagon River is frequently affected by human influence. The site is used for fishing and other recreational activities. Also, an artificial dam is located between Cisco Lake and the head of the river.

Experimental Design and Data Collection

Riparian Study:

Width and average depth (taken at 0.25, 0.50, and 0.75 of the width) was taken at 27 sites on Kickapoo/Brown Creek (Figure 2). Percent cover of emergent, submergent, and floating vegetation was recorded at each site. Riparian species presence was also recorded at each site. Plant species were marked (1-30) and collected in plastic bags in the field to be identified (Voss, E.G., 1972; Voss, E.G., 1985) in the lab.

Fish Diversity Study:

On the West Branch Ontonagon River, fish diversity was taken at 4 different sites (Figure 3). Backpack electrofishing was used to sample a riffle, a pool, and a run at each site. It is argued that focusing on one environment can minimize variation and ensure consistency amongst habitat comparisons (Albanese *et al.*, 2004; Paukert, 2004). However, sampling riffles, pools, and runs offered a more accurate level of biodiversity within the West Branch Ontonagon River. It also allowed for the study to not only compare fish diversity at various distances from Cisco Lake, but also habitat preference at each distance. Shocking was performed in a 6.5x3 meter area within each environment at each site. A seine net was placed downstream of each shocked sample site to help ensure accurate estimates of the large number of small fish within the West Branch Ontonagon River (Paukert, 2004). A hand net was used to capture larger fish that were shocked. Shocking lasted 6 minutes at each habitat within each site; the seine netting was removed every 2 minutes a total of 3 times to collect the captured fish. Stunned fish were collected in buckets. Fish were identified (Page and Burr, 1991; Bailey *et al.*, 2004), weighed, measured (length), and rereleased on site.

Analysis:

Species richness was determined for riparian vegetation in Kickapoo Stream. A regression was used to look at changes in species richness with increasing distance from Kickapoo Lake and width. Three regressions were run interpret the changes in percent composition of emergent, submergent, and floating vegetation as distance from Kickapoo Lake increased.

For an insight into fish species richness within the West Branch Ontonagon River, a two-way ANOVA was used to see how species richness differed with site (1-4) and habitat (riffle, pool, or run). For fish biodiversity, Shannon Diversity Index was used to determine diversity coefficients. Then, a two-way ANOVA was run to look at how diversity differed with site and habitat. Wilk's Lambda (MANOVA) was used to look at the relationship between fish length and mass in Redtail Chubs, a highly abundant species, within each site and habitat in the West Branch Ontonagon River). Hotelling's T-Square test was also run to determine how the sites and habitats compared to the mass/length relationship of Redtail Chubs.

Results

Along Kickapoo Stream, there was a strong correlation of riparian species richness to increasing distance from Kickapoo Lake and increasing stream width (Figure 4). A regression illustrated this significance [$F_{df(2), df(24)}$=10.994, P< 0.001], based on a standard significant p-value as P<0.05. A regression on percent coverage at increasing distances from Kickapoo Lake was conducted for each major form of riparian vegetation: floating, submergent, and emergent (Westlake, 1975). None of the regressions showed increasing distance from Kickapoo Lake to be a significant factor in percent coverage of riparian vegetation (floating: [$F_{df(1), df(25)}$=0.134, P=0.718], submergent: [$F_{df(1), df(25)}$=1.268, P=0.271], and emergent: [$F_{df(1), df(25)}$=1.570, P=0.222]).

Species richness was also calculated for fish in the West Branch Ontonagon River. A two-way ANOVA showed that there was no significance in habitat [$F_{df(2), df(5)}$=1.656, P=0.281] or site [$F_{df(1), df(5)}$=2.329, P=0.188] on fish species richness. There was also no significance seen in habitat [$F_{df(2), df(5)}$=0.628, P=0.571] or site [$F_{df(1), df(5)}$=0.000, P=0.988] on fish diversity.

Redtail Chubs were used to describe the intraspecific variations in fish size amongst habitat and site. Redtail Chubs were used because they were found in high abundances and were distributed amongst all sample sites. Chub mass showed a direct positive correlation to Chub length (P<0.001). This result was not surprising, since it is well known that a longer fish within the same species will most likely have a greater mass. However, this correlation led to a

Wilk's Lambda multivariate test, which showed a strong significance of site on Redtail Chub length and mass [$F_{df(6), df(208)}$, P<0.0001] and a strong significance of habitat on Redtail Chub length and mass [$F_{df(4), df(208)}$, P=0.005543].

Based on this correlation, a post-hoc Hotelling's T-square test was run on habitat and site. For site, there was significance amongst all sites (P<0.05), except for between sites 1 and 3 (P=0.160626), indicating similar mean values for Redtail Chub mass and length between sites 1 and 3 (Figure 5). For habitat, there was significance between pools and riffles (P=0.006592) and pools and runs (P=0.012070), but not between riffles and runs (P=0.083064) on Redtail Chub mass and length. This result shows how pools were different in Chub mass and length correlation compared to runs and riffles, but that runs and riffles had similar mean values of Redtail Chub mass and length (Figure 6).

Discussion

Riparian vegetation on Kickapoo Stream showed a significant difference in species richness based on distance away from Kickapoo Lake (P<0.001), but there was no correlation of stream distance to percent coverage of emergent, submergent, or floating vegetation. These findings are the reverse of the original hypothesis that species richness would remain constant and that riparian coverage would vary with increasing distance from Kickapoo Lake. Reasoning for constant riparian vegetation coverage values for Kickapoo Stream could have been due to the stream only reaching from 1^{st} order to 2^{nd} order before flowing into Brown Lake. The RCC predicts visible changes in riparian coverage occurring over longer segments in a stream (Figure 1). Also, Kickapoo Stream is surrounded by grasslands, with virtually no canopy cover. As a 1^{st} order stream, this study of Kickapoo Stream does not follow the model set by the RCC. This revelation could illustrate that predictions of the River Continuum Concept cannot be used in streams with high light intensity. With minimal shading throughout the entire sampled area and negligible flow rate (Allan, 1995), floating and submergent vegetation was able to grow in high abundance heedless of sample site. The variation in species richness with increasing distance from Kickapoo Lake was very interesting. Since Kickapoo Stream came into contact with Brown Lake to become a 2^{nd} order stream it might have been introduced to new species brought from Palmer Lake (the source of Brown Stream).

For the study on the West Branch Ontonagon River, there was no significance of habitat ($P=0.281$) or site ($P=0.188$) on fish species richness. There was also a lack of significance of site and habitat on fish diversity. There is generally a shift in abundance with various locations on a stream rather than species absence (Vannote *et al.*, 1980). The lack of changes in species richness and diversity based on site and habitat could have been due to the relatively small section of stream sampled (≈12 miles). Without a long enough sample reach of the West Branch Ontonagon River, a shift in abundance might not of have yet occurred. Also, without an increase in order, new species introduction would have also prevented contribution to an increased species richness or diversity. A third factor that could have led to low levels of fish diversity could have been the human influence of the West Branch Ontonagon River acting as a stress factor that some fish might not have been able to handle.

However, the lack of significance on fish diversity due to habitat ($P= 0.571$) was surprising. Fish are often specialized physiologically based on habitat type. Fast swimming fish and fish that swim in fast currents (riffles) are generally streamlined and rounded in cross section (Allan, 1995), allowing for mobility in the rapidly moving water. This specialization leads to many species localizing mainly in riffles or pools, but seldomly in both (Allan 1995). Exceptions to this stem from changes in life stages. To look at the distribution of fish based on life stage, Redtail Chub (a common fish within the West Branch Ontonagon River) was measured and weighed in each habitat within each site.

There was a significance of site on Redtail Chub length and mass for all sites except between sites 1 and 3 (P=0.160626). There was a large beaver dam directly before site 3's sampled habitats. Headwater dams greatly decrease the nutrient availability below the impoundment because of the blocking of detritus transport (Ward and Stanford, 1983). Redtail Chubs in site 3 might not have had the nutrients to reach the larger sizes that would be expected for fish at their location on the West Branch Ontonagon River. Because of this, Chub mean mass and length values for site 3 were closer to mean values found in site 1 (Figure 5), where fish were most likely in earlier life stages and of smaller size (Albanese *et al.*, 2004). Chub mass and length in site 4 was not visibly affected by this nutrient deprivation (Figure 5) because there was most likely a large enough area between the two sites to reaccumulate detritus and other nutritional food sources.

The significance of habitat on Redtail Chub length and mass was seen between pool and riffle, and pool and run habitats (Figure 6). However, there was no significance found between riffle and run habitat type (P=0.083064). This could have largely been due to substrate type seen amongst habitats. Clean stony riffles generally express greater species richness when compared to pools with silt substrate. Yet, riffles and pools that both contain gravel and larger material show little difference in species richness (Allan, 1995). The runs and riffles in the West Branch Ontonagon River both had rocky substrates, while the pools that were studied consisted of silty substrate. This study only determined differences in habitat on current flow. In further studies, substrate should be considered when determining fish diversity.

To serve as an indicator of stream health, surveys of riparian vegetation and fish within streams would need to cover a larger area than time constraints of this study allowed. This study did provide insight into possible disturbances (e.g. damming) on biological response, such as fish size. An obstacle with the fish diversity study on the West Branch Ontonagon River was that study sites were selected by accessibility. This created sites that were not a equivalent distances from one another (Figure 3). A study with evenly distributed sites would allow a more accurate gradient on fish assemblage based on distance from a mainsource lake.

It would have been interesting to compare fish diversity of the West Branch Ontonagon River (impacted by humans) to the fish diversity of Kickapoo Stream (not impacted by humans). However, floating and submergent vegetation on Kickapoo Stream were too dense to capture stunned fish. Further studies should observe human impact (Mazeika, 2008) and natural disturbances (Montgomery, 1999) on stream ecosystems. This information can lead to conservation focus points to maintain a healthy freshwater resource.

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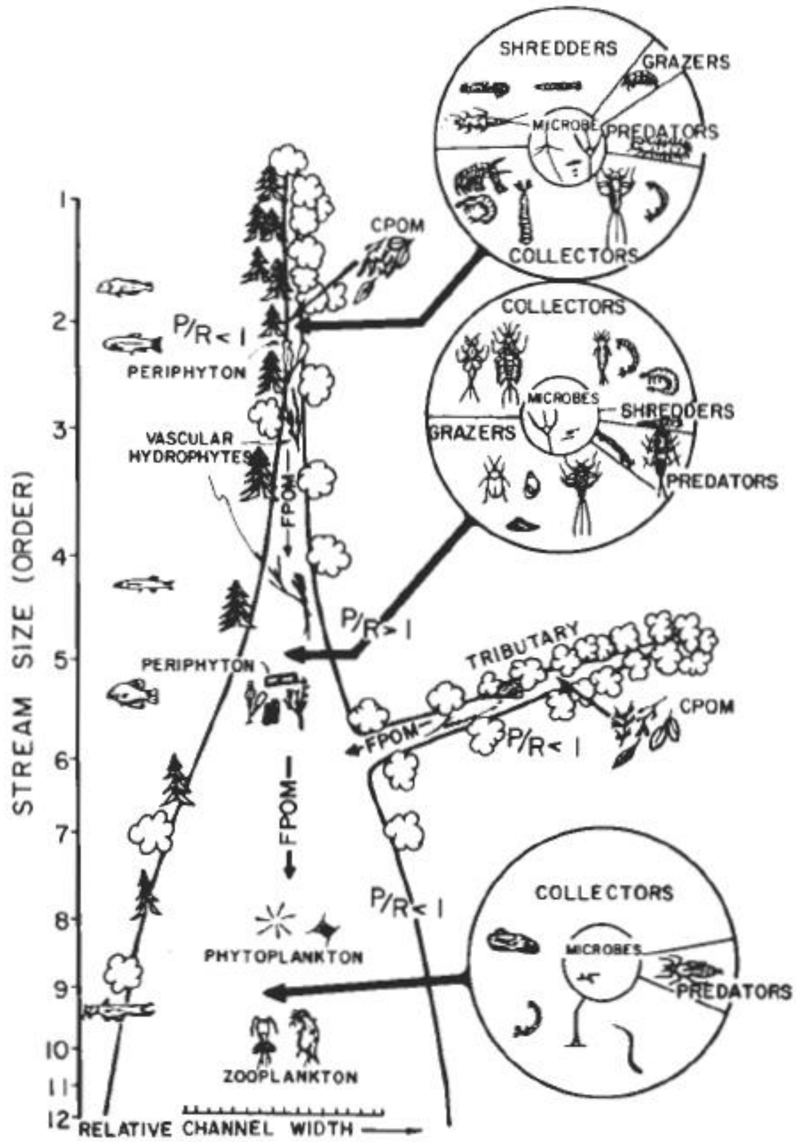

Figure 1. River Continuum Concept (RCC): A model to describe the relationship between stream size based on order and the shift of various lotic communities (Vannote *et al.,* 1980).

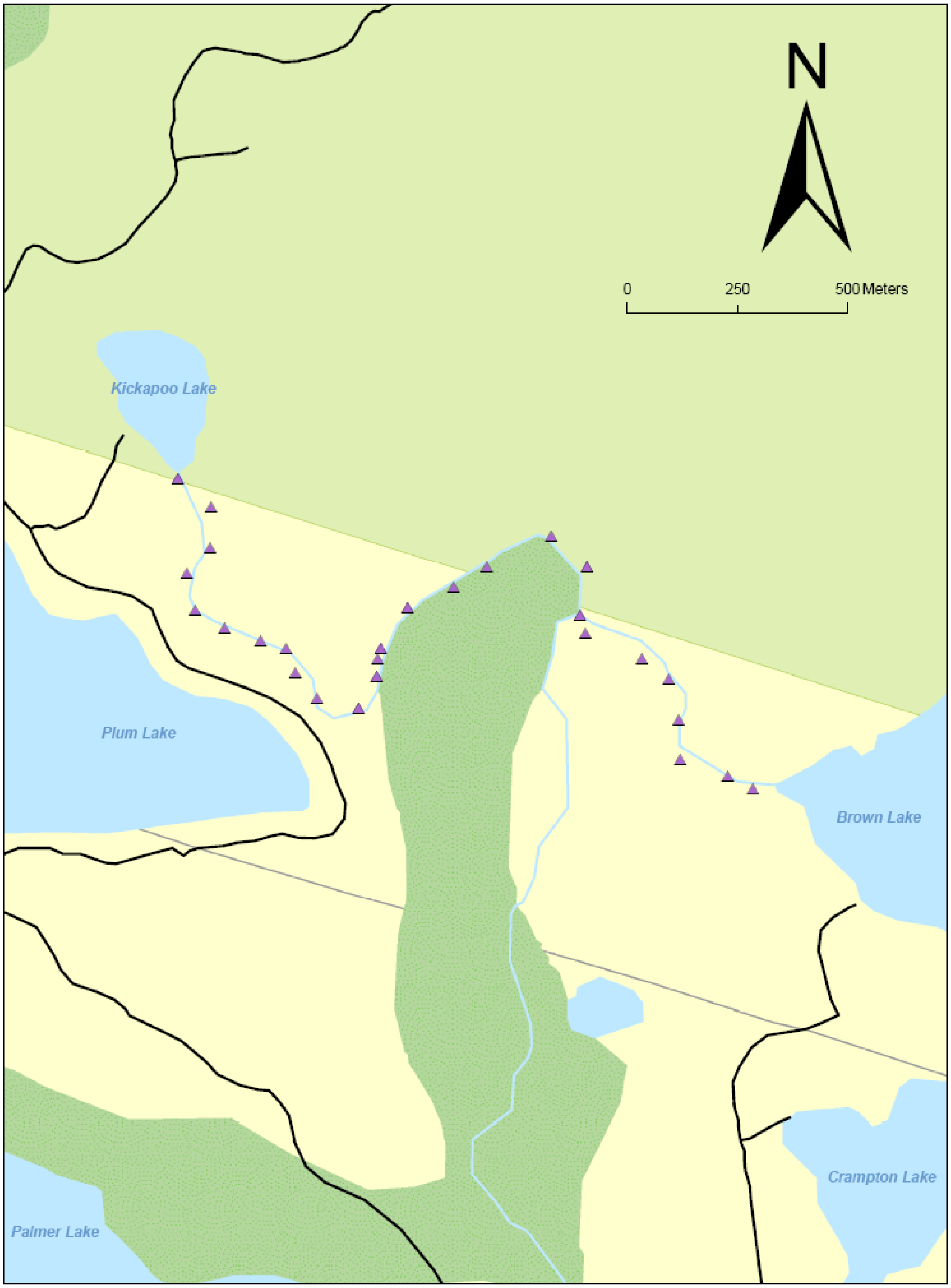

Figure 2: Map of Kickapoo Stream from Kickapoo Lake to Brown Lake. Purple triangles indicate sample sites of riparian vegetation and width and depth measurements.

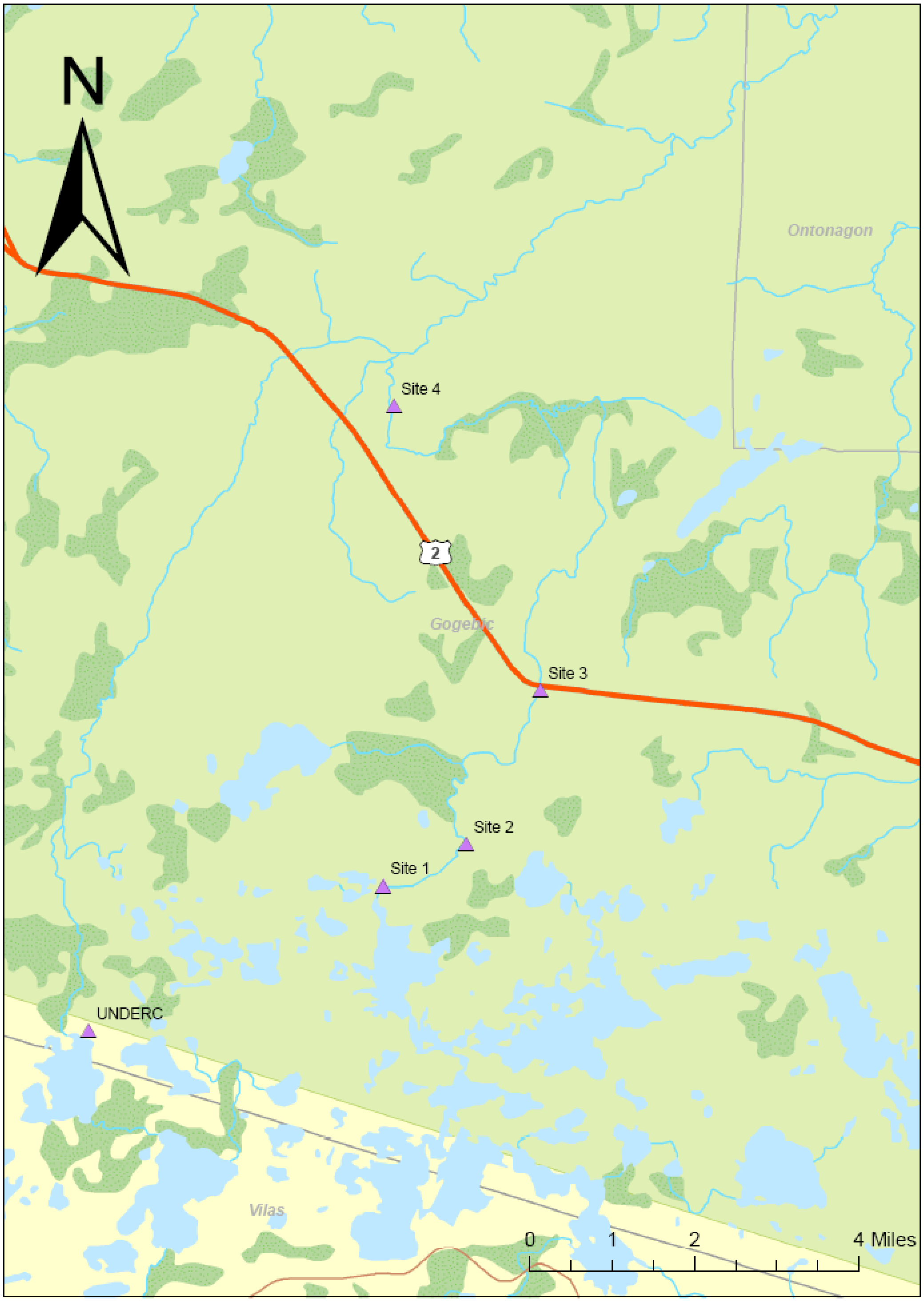

Figure 3. Map of the sampled section of the West Branch Ontonagon River flowing from Cisco Lake in the Ottawa National Forest. Purple triangles along the stream indicate sample sites of fish diversity and Redtail Chub size. A purple triangle also represents the location of the University of Notre Dame Research Center.

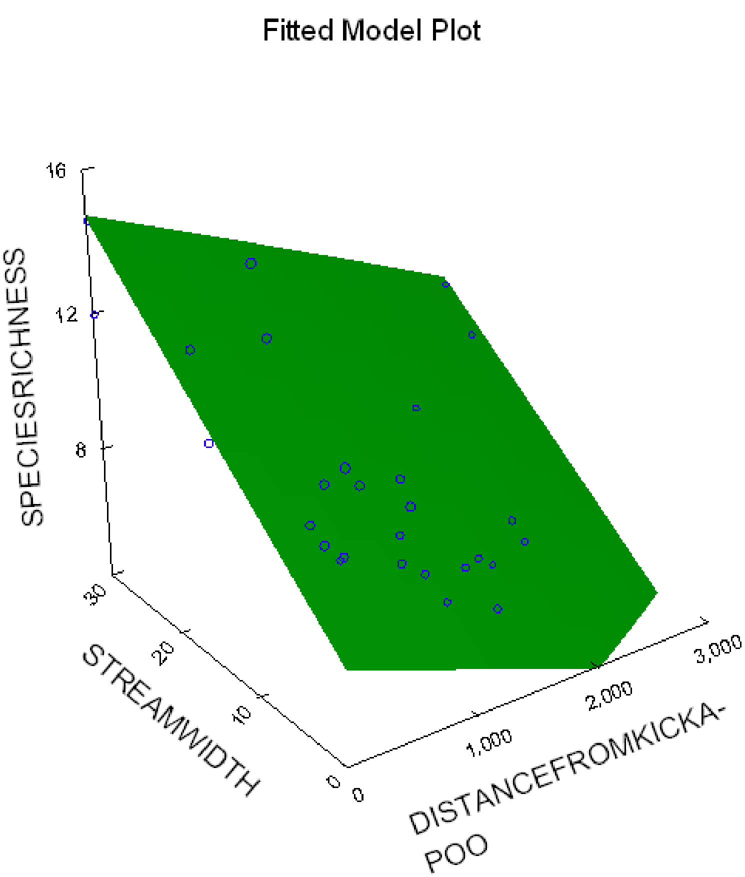

Figure 4. A 3-D representation of riparian species richness along Kickapoo Stream with increasing distance from Kickapoo Lake (a total of 2292 meters) and stream width.

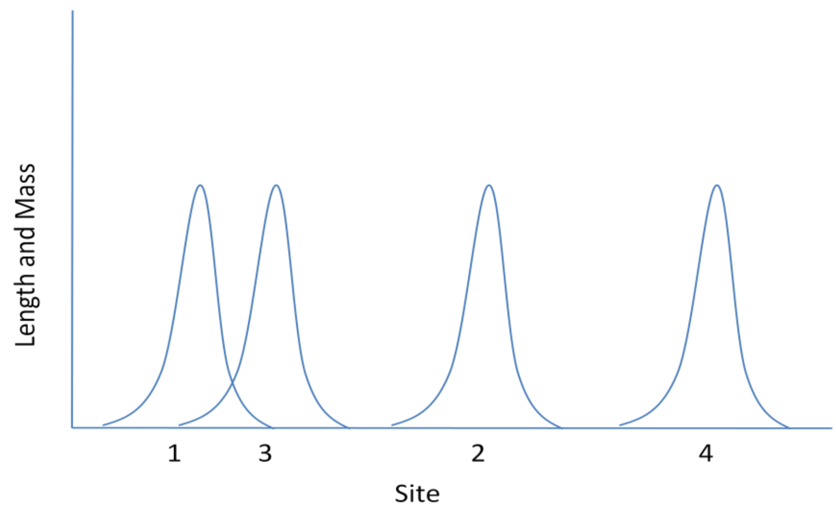

Figure 5. A visual interpretation of difference in mean mass and length values of Redtail Chubs at different sites (1-4) on the West Branch Ontonagon River; with each site getting progressively further from Cisco Lake.

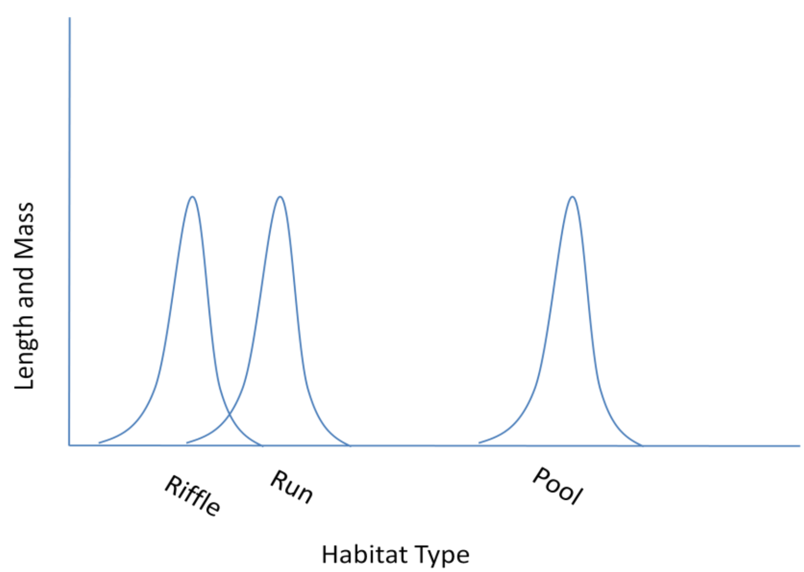

Figure 6. A visual interpretation of difference in mean mass and length values of Redtail Chubs at different habitats (pool, riffle, and run) on the West Branch Ontonagon River.