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ECOSYSTEM STRUCTURAL AND FUNCTIONAL INDICATORS TO EVALUATE CONSERVATION EASEMENT SUCCESS IN THE HORSE CREEK WATERSHED NEAR THE GRAND LAKE O' THE CHEROKEES, OKLAHOMA

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ECOSYSTEM STRUCTURAL AND FUNCTIONAL INDICATORS TO EVALUATE CONSERVATION EASEMENT SUCCESS IN THE HORSE CREEK WATERSHED NEAR THE GRAND LAKE O' THE CHEROKEES, OKLAHOMA

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BY THE COMMITTEE CONSISTING OF

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ABSTRACT

Stream restoration activities in the United States commonly seek to improve aquatic and riparian structure. Traditional assessment methods evaluate ecosystem structure by estimating metrics such as biotic community assemblages, stream flow regimes, and riparian vegetation. However, very few assessments incorporate measures of ecosystem function, such as decomposition and productivity. In the Horse Creek watershed near the Grand Lake o' the Cherokees in northeastern Oklahoma, stream restoration efforts take the form of cattle exclusion fences to address impaired stream habitat and water quality, and to decrease stress from livestock grazing on riparian vegetation. This study seeks to assess the impact of these conservation easements on ecosystem structure and function. Three sites were selected in the Horse Creek watershed, one within the conservation easement area and two outside of the exclusion fences. A reference stream, Fivemile Creek, was identified in the region for comparison. A geographic information system (GIS) evaluation of land use and land cover in the watersheds highlights a great degree of agricultural land use in the Horse Creek watershed, and a lesser anthropogenic impact in the Fivemile Creek watershed. Habitat assessments indicated that overall structural habitat quality was greatest at the reference site, lower in the conservation easement treatment site, and were the lowest at the two control sites. Fish and macroinvertebrate results indicate the greatest scores for biotic indices at the reference stream, followed by the conservation reach at Horse Creek, then the control reach. A remote sensing study of the watershed indicated that Normalized Difference Vegetation Index (NDVI) values increased during a two-year time interval in two of the three fenced-in conservation easement reaches, and aboveground biomass increased in all three fenced-in reaches. Ecosystem function was evaluated by estimating productivity and respiration through diel dissolved oxygen changes, and a cotton strip assay was conducted to evaluate rates of decomposition. Net primary productivity did not correlate to water quality, habitat metrics, or land use. Decomposition rates were lowest in the reference stream, were greater in the conservation easement site, and were greatest outside of the conservation easements. Results of metabolism and decomposition studies were treated as dependent variables and compared to physicochemical water quality parameters, watershed land use, and habitat metrics. These results support the use of cattle exclusion conservation easements to improve impaired water and habitat quality in the Horse Creek watershed.

Chapter 1 – Introduction

Stream quality, both in regard to ecosystem health and water quality, are inexorably linked to land use in a given watershed (Meneses et al. 2015). Nonpoint-source pollution from agricultural or urban land use creates complex impacts on stream ecosystems (Smith et al. 2012; Yu et al. 2013). Land use intensification generally increases nonpoint source pollution inputs to stream systems, including nutrients, sediment, and bacteria (DeLong and Brusven, 1991). Concerns over the degradation of streams lead to billions of dollars spent annually on rehabilitation and restoration projects, with federal spending conservatively estimated at $1.9 billion per year (BenDor et al. 2015).

A large variety of restoration techniques (Roni et al. 2008) are applied to degraded stream ecosystems, including interventions such as riparian fencing (Grudzinski et al. 2020), streambank stabilization (Sudduth and Meyer 2008), or in-stream habitat improvement (Li et al. 2018). Understanding the effectiveness of stream restoration techniques is necessary for cost-effective design and implementation, and the evaluation of completed projects can be used to improve future endeavors. However, stream restoration projects are rarely evaluated after completion (Rubin et al. 2017).

Assessment of stream systems is often conducted by following standard methods outlined in the US EPA Rapid Bioassessment Protocols (Hughes et al. 2009). These methods provide the frameworks necessary for quantifying aquatic life and habitat data for water quality management purposes. Data generated are frequently used to evaluate potential causes of stream degradation and to monitor these trends over time (Shupryt and Studinski, 2021; Linke et al. 1999). Structural approaches evaluate streams to classify the natural variability of physical stream features (USACE 2004). These evaluations of stream reaches are often used to compare biotic indices to the physical structure of the instream and riparian habitat – which include metrics such as substrate size, instream woody debris, bank erosion, or canopy cover – to determine potential sources of impairment (Doll 2011).

However, very few stream assessments evaluate in-stream and riparian ecological function. Riparian ecosystems are transitional between aquatic and terrestrial environments, and provide a wide range of ecological functions, such as nutrient cycling and organic matter decomposition, that influence both habitat and stream water quality (Stutter et al. 2021; Burdick et al. 2021). Although riparian areas only account for a small portion of land use, they are vital for ecosystem function and benefits to human society (Vidon et al. 2018). Riparian areas are generally structurally diverse and highly productive, providing ecosystem services such as wildlife habitat, water quality improvement, migration routes, and erosion control (Gregory et al. 1991; Bodie 2001). These systems are dynamic and are subject to a variety of stresses, including droughts, floods, stream channel incision, and grazing (Swanson et al., 2015). Cattle may be allowed to utilize riparian areas for water supply and for feeding, as these areas provide green forage longer than the surrounding uplands (Parsons et al., 2003). However, unrestricted grazing removes desirable vegetation, compacts soil, and can cause bank erosion. Removal of ground cover limits the ability of the riparian area to filter sediments, bacteria, and nutrients from reaching the stream. The end result is erosion and degradation in water quality (Kansas Forest Service, 2006).

Poor stream health can be described by changes in ecosystem metabolism due to riparian changes, such as increased gross primary productivity (GPP) due to nutrient enrichment or warmer water temperatures (Giling et al. 2013). Effective conservation requires the assessment of the quantity and quality of functions provided by riparian ecosystems (Hunter 2005). Direct measurements of ecological structure, such as site-specific species surveys, are readily understood and easily communicated but can be expensive and time-consuming. Evaluations based on functional indicators can be comprehensive and address numerous ecological functions (Suter 1993).

The remainder of this thesis addresses specific efforts to assess riparian ecosystem structure and function. Chapter two, “Characterization of the Horse Creek Watershed of the Grand Lake o’ the Cherokees, Oklahoma” describes a small, agriculturally-dominated sub-watershed near Afton, Oklahoma. The chapter characterizes the Horse Creek watershed, evaluating land use, land cover, and habitat due to the implementation of cattle exclusion fencing along a conservation easement. The results of the GIS assessment are discussed and used as part of other studies in this study. Chapter three, “Biota in the Horse Creek Watershed of the Grand Lake o’ the Cherokees, Oklahoma” evaluates fish and macroinvertebrate assemblages in Horse Creek, riparian vegetation recovery within the conservation easement, and compares biotic metrics to Fivemile Creek, a reference stream in the region. Finally, chapter four, “Ecosystem Metabolism and Function in the Horse Creek Watershed of the Grand Lake o’ the Cherokees, Oklahoma” evaluates the impact of the establishment of cattle exclusion fencing and conservation easements on net primary productivity (NPP) and decomposition (as cotton tensile strength loss) rates in Horse Creek. These are also compared to the regional reference stream Fivemile Creek.

Chapter 2 - Characterization of the Horse Creek Watershed

Abstract: Horse Creek is a small, agriculturally dominated watershed that drains into Grand Lake o’ the Cherokees in northeastern Oklahoma. Cattle exclusion conservation easements were installed with the cooperation of landowners in the watershed, removing 1.1 km^2 of riparian area from agricultural production. This study conducted land use and land cover characterizations from satellite-derived geospatial data and compared these land use categories to a regional reference stream, Fivemile Creek. The Horse Creek watershed is dominated by agricultural land use, which comprises 89% of the land area in the basin. Habitat assessments were conducted to quantify habitat structure in three reaches in Horse Creek and a fourth reach in Fivemile Creek. Major impairments to Horse Creek habitat, in comparison to Fivemile Creek, include lack of flow variability and decreased riparian zone vegetative width.

Keywords: Conservation Easement, Cattle Exclusion, NLCD, Habitat Assessment, Riparian Structure

2.1. Introduction

According to the Oklahoma Water Resources Board (OWRB), Horse Creek is a sub-watershed of Grand Lake o’ the Cherokees in Ottawa County and northern portions of Delaware County, Oklahoma (OWRB 2001). Two sub-watersheds, Upper Horse Creek (HUC12 110702060402) and Lower Horse Creek (HUC12 110702060403), drain 127 and 93 square kilometers of land area, respectively. Two streams, Horse Creek and Little Horse Creek, drain the Upper Horse Creek sub-watershed, while Horse Creek and Fly Creek drain the Lower Horse Creek sub-watershed. The town of Afton, Oklahoma lies within the Upper Horse Creek sub-watershed (Figure 1; NLCD 2019).

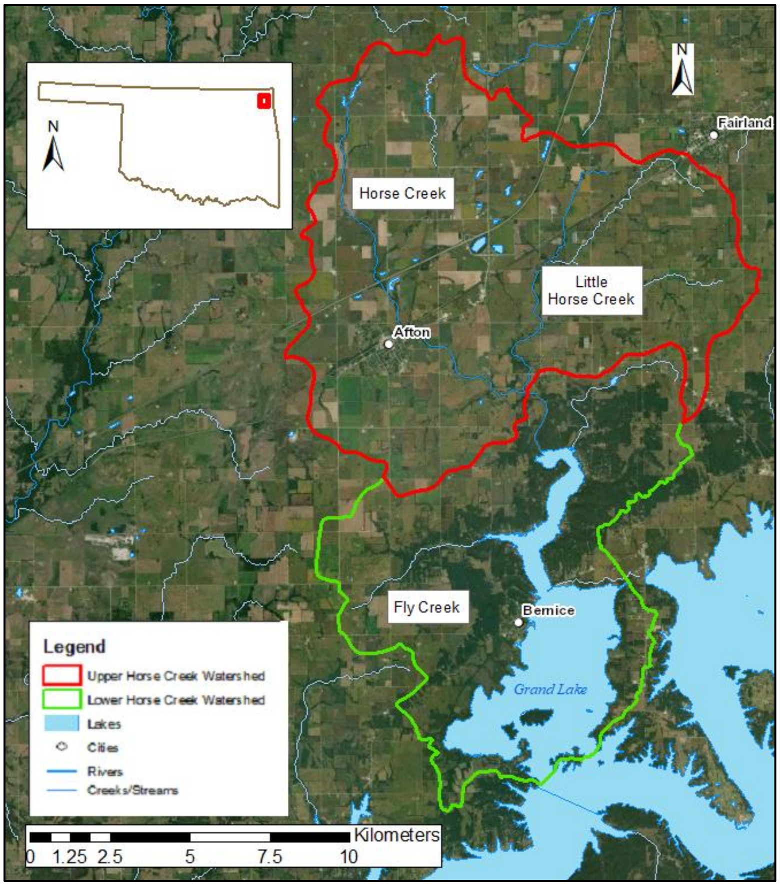


Figure 1: The Horse Creek Watershed, including Horse Creek, Little Horse Creek, and Fly Creek.

Since 2011, the Grand River Dam Authority (GRDA), which manages Grand Lake o' the Cherokees, has issued cyanobacteria advisories during the summer months when necessary (Krehbiel 2020). These phototrophic cyanobacteria can produce toxins that are harmful to both humans and wildlife, and can negatively affect the taste and odor of the water (Bláha et al. 2009). Many of the harmful algal blooms (HABs) that have occurred in Grand Lake o' the Cherokees originated in the Horse Creek arm of the lake (Nikolai and Dzialowski 2014; Mason and Triplett 2016; Morrison et al. 2017). GRDA staff have hypothesized that land use in the Horse Creek watershed has contributed significant nutrient loads to the lake, causing eutrophication and resulting in HABs (GRDA 2008). HABs occur in warm, calm waters in the presence of excess nutrients, such as nitrogen and phosphorus. HABs in Grand Lake o' the Cherokees negatively impact recreation and tourism, and have been documented to create health risks for people living near the lake (Boyer et al. 2017). Aside from HABs, Horse Creek and Little Horse Creek are listed on the Oklahoma Department of Environmental Quality's 303(d) list of impaired waterways. Dissolved oxygen, *E. coli*, sulfate, and macroinvertebrate biotic assemblages are impaired, likely due to agricultural and other anthropogenic activities in the watershed. Direct cattle access to streams may contribute significantly to erosion and bacterial inputs (O'Callaghan et al. 2018).

Fencing of riparian zones is a common rehabilitation approach in degraded pasture streams. By excluding livestock access to streams, bank erosion and direct fecal bacteria input to the streams may be decreased, and the vegetation in the riparian zone may be re-established by planting or volunteer reestablishment (Doehring et al., 2019). In Oklahoma, participation in riparian fencing practices is promoted through the use of the Conservation Reserve Enhancement Program (CREP). The Oklahoma Conservation Commission (OCC), in collaboration with the U.S. Department of Agriculture, provides annual rental payments to landowners to remove riparian areas from production and establish exclusion fencing (Oklahoma Conservation Commission, 2015).

In 2018, the GRDA and the OCC successfully entered into conservation agreements with landowners in the Horse creek watershed, where 1.1 km^2 of riparian land was fenced and removed from cattle grazing production, southeast of the town of Afton (Arango 2020). Cattle exclusion is a widespread riparian rehabilitation method in agricultural areas (Line et al. 2000). These conservation easements are designed to improve water quality and habitat by protecting the riparian corridor associated with Horse Creek. The main purpose of this study was to evaluate watershed conditions in the Horse Creek watershed. Land use/land cover data were used to help describe sub-watershed impacts of land use on study sites. Habitat assessments were used to evaluate stream and riparian corridor conditions.

2.2. Materials and Methods

2.2.1. Study Areas

The area of research for this project is the Horse Creek watershed of the Grand Lake o' the Cherokees, near Afton, Oklahoma (36.6802º N, -94.9255º W). Horse Creek is a third-order stream in the Ozark Highlands ecoregion (US EPA 2013). The watershed is characterized by a continental climate with hot, dry summers and cool winters. The area receives an average of 114 centimeters of precipitation per year, with an average summer high temperature of 32 degrees C and an average winter low temperature of -4 degrees C (Oklahoma Climatological Survey, 2017). Cattle exclusion fencing was installed as part of a conservation easement in the watershed. The study easement encloses 69.13 hectares of land around the creek (Figure 2; Arango 2020).

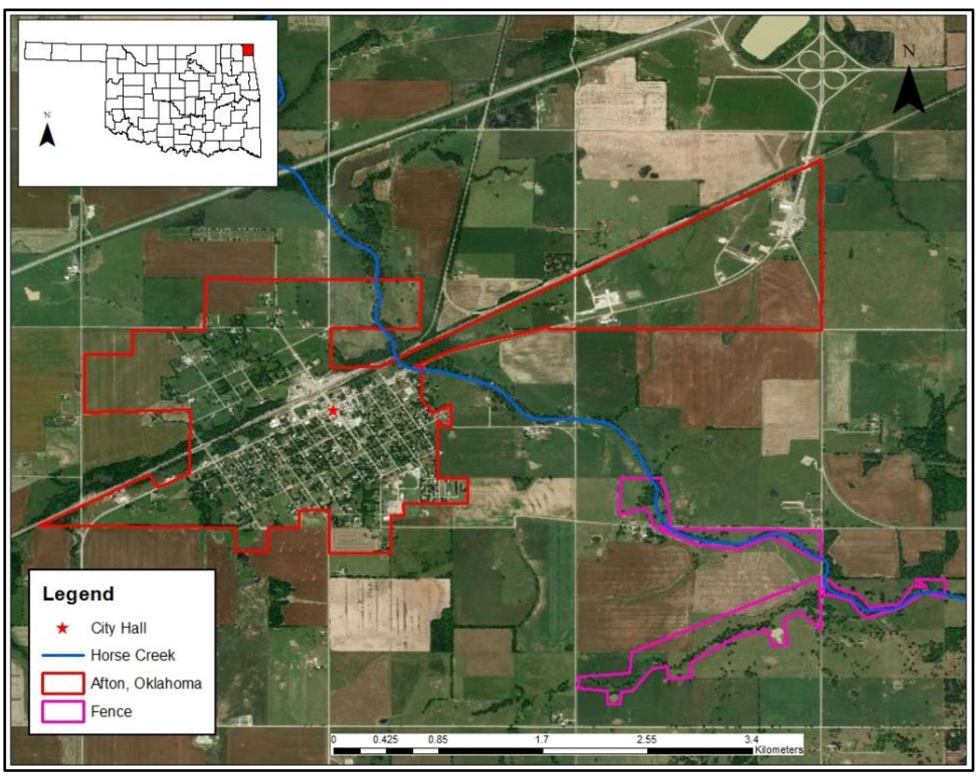


Figure 2: The location of the conservation easements on Horse Creek (pink) relative to the town of Afton, Oklahoma (red).

This study also utilizes a regional reference stream. Fivemile Creek is a 3rd-order tributary of the Spring River in the Ozark Highlands ecoregion, with its watershed in Ottawa County in the northeastern corner of Oklahoma and a western portion of Missouri. The area receives an average of 114 centimeters of precipitation per year, with an average summer high temperature of 33°C and an average winter low temperature of -5°C (Oklahoma Climatological Survey, 2017). Fivemile Creek was identified as a regional reference through the OCC Rotating Basin Program, a monitoring program for state streams. Through analysis of various water quality parameters, the OCC has indicated that Fivemile Creek is comparable to high quality streams in the ecoregion for all parameters except for macroinvertebrate community assemblages and instream/riparian habitat, both of which did not score as high-quality sites but were not considered to be impaired (Oklahoma Conservation Commission 2008).

The study reach at Fivemile is visually different from the Horse Creek reaches, especially in terms of water clarity and substrate composition. Where the Horse Creek watershed is characterized by low baseflow, turbid water, and bedrock substrates, Fivemile Creek has clear water, cobble substrate, and a comparatively high baseflow. In the summer months of 2022, Horse Creek experienced a prolonged period of no measurable flow at a USGS gaging station due to lack of precipitation. However, the Fivemile watershed had constant flow at the sampling site, even through the driest months.

2.2.2. Geographic Information System Data

2.2.2.1. Land Use/Land Cover

Land use and land cover refer to physical features on the surface of the Earth – such as vegetation, water, and urban development. Images generated from remote sensing are divided into cells, and each cell is assigned a specific category of land use (Parece and Campbell 2015). These thematic classes are generated by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of various federal agencies to produce consistent land cover information (MRLC, 2019). The consortium produces a product, known as the National Land Cover Database (NLCD), with the most recent dataset having been generated in 2019. This dataset provides 20 classes of land use (MRLC 2019, Table 1).

Table 1. NLCD land use classes and descriptions.

Value	Classification	Description
11	Open Water	Areas of open water
12	Perennial Ice/Snow	Perennial cover of ice or snow
21	Developed, Open Space	Impervious surface <20%
22	Developed, Low Intensity	Impervious surface 20 – 49%
23	Developed, Medium Intensity	Impervious surface 50 – 79%
24	Developed, High Intensity	Impervious surface >80%
31	Barren Land	Rock/sand/clay, vegetation <15% of cover
41	Deciduous Forest	More than 75% of tree species deciduous
42	Evergreen Forest	More than 75% of tree species evergreen
43	Mixed Forest	Neither deciduous nor evergreen species dominate
51	Dwarf Scrub	AK-only areas dominated by shrubs < 20cm tall
52	Shrub/Scrub	Areas dominated by shrubs
71	Grassland/Herbaceous	Areas dominated by herbaceous vegetation
72	Sedge/Herbaceous	AK-only areas dominated by sedges and forbs
73	Lichens	AK-only areas dominated by lichens
74	Moss	AK-only areas dominated by mosses
81	Pasture/Hay	Areas managed for livestock grazing or hay crops
82	Cultivated Crops	Areas managed for annual crops
90	Woody Wetlands	Soil periodically saturated with water, >20% forest or shrub vegetative cover
95	Emergent Herbaceous Wetlands	Soil periodically saturated with water, >80% perennial herbaceous vegetative cover

2.2.2.2. Watershed Boundaries

The United States Geological Survey (USGS) has delineated each of the major watershed basins in the United States. The Watershed Boundary Dataset (WBD) delineates each of these watersheds based on a Hydrologic Unit Code (HUC) that ranges from 2 to 12 digits, describing where the unit is in the country and the size of the basin (USGS, 2017). For this study, HUC12 (sub-watershed scale) shapefiles representing Upper Horse Creek (HUC12 110702060402 and Fivemile Creek (HUC12 110702071001) were used (USGS 2017).

2.2.2.3. Digital Elevation Model

A digital elevation model (DEM) is a representation of the bare ground topographic surface of the Earth, which excludes trees, buildings, and other surface objects (Garbrecht and Martz, 2000). DEMs are generated by the USGS with high-resolution interferometric synthetic aperture radar ("IFSAR") data. These data normally consist of square grid cells with elevation given to each cell as an attribute (Zhang and Montgomery 1994). In GIS software, this two-dimensional grid is used to represent the three-dimensional surface of the Earth, and is useful for hydrologic monitoring, resource monitoring, and mapping. For this portion of the study, two DEMs were required, encompassing the region around the Horse Creek watershed and the Fivemile Creek watershed (USGS 2021; 1/3 arc second "n37w095" and "n38w095").

2.2.3. Habitat Assessments

The evaluation of habitat quality provides information on the quality of in-stream and riparian zone structure and function of the lotic aquatic community (OCC 2006). The OCC follows a modified EPA Rapid Bioassessment Protocol (Barbour et al. 1999), supplemented by other documents. The assessment is based on three categories of parameters: microscale habitat, including bottom substrate and flow; macroscale habitat, such as channel morphology and sinuosity; and riparian and bank structure, for example bank vegetation and streamside cover.

Scores are assigned as an evaluation of in-stream conditions over a 400-m reach of stream, with 20 measurements made over 20-m intervals.

2.2.4. Methods

2.2.4.1 GIS Evaluation of the Watershed

Characterization of the Horse Creek and Fivemile Creek watersheds was completed using ArcGIS Pro software. Data included land use/land cover data from the National Land Cover Database, HUC12 watershed shapefiles, 2-meter IFSAR-derived digital elevation models, and GRDA-generated Horse Creek Conservation Easement shapefiles. The HUC12 watershed shapefiles were loaded into the map, and the shapefiles for Upper Horse Creek, Lower Horse Creek, and Fivemile Creek were individually selected. New shapefiles were created from each of these sub-watershed shapefiles. The NLCD 2019 Land Cover raster was imported to the map, then the Clip Raster (Data Management) function was applied to clip the NLCD 2019 dataset to each of the three sub-watersheds individually, maintaining the use of input features for clipping geometry. USGS IFSAR-derived 2-meter DEM data for the 1/3 arcsecond regions encompassing Horse Creek and Fivemile Creek were imported to the map and similarly clipped using the Clip Raster function, maintaining the use of input features for clipping geometry. Once clipped, the original HUC12 shapefile, the NLCD 2019 dataset, and 2-meter DEM files were removed.

To improve the ability of ArcGIS Pro to evaluate water flow in the DEM files, the Fill tool was used to remove sinks with an undefined drainage direction in the watershed (ArcGIS 2022). This effort improves the ability of the Flow Direction tool to evaluate primary channels. The Flow Direction tool was run on each of the three DEM raster images to evaluate cell-to-cell flow direction, known as the “D8” method. The flow direction raster datasets were imported into the

Flow Accumulation tool, which calculated accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the raster. The result of the Flow Accumulation process was a high-resolution raster showing the flow accumulation path representing the streams in each of these sub-watersheds. Streamlines generated by the Flow Accumulation tool were used to delineate sub-watersheds using the Watershed tool, with each of their pour points set to each sampling location.

2.2.4.2. Habitat Assessment

Habitat assessments followed the OCC Habitat Assessment Standard Operating Procedure (OCC, 2006). In summary, the habitat assessment was conducted along a 400-meter reach of stream in which the area is of interest or is determined to be representative of the overall condition of the stream. A field form was filled out containing the site name, date, starting point, end point, sinuosity of the stream, the investigators, and the direction of investigation (upstream or downstream). Three sites (the treatment site and both control sites) were evaluated at Horse Creek (Figure 3); another transect was evaluated at Fivemile Creek. Horse Creek North ("HCN") and Little Horse Creek ("LHC") were used as control sites for subsequent tests; Horse Creek East ("HCE") was used as the treatment site, since it was a part of the riparian conservation easement; Fivemile Creek ("5MI") was used as the reference site.

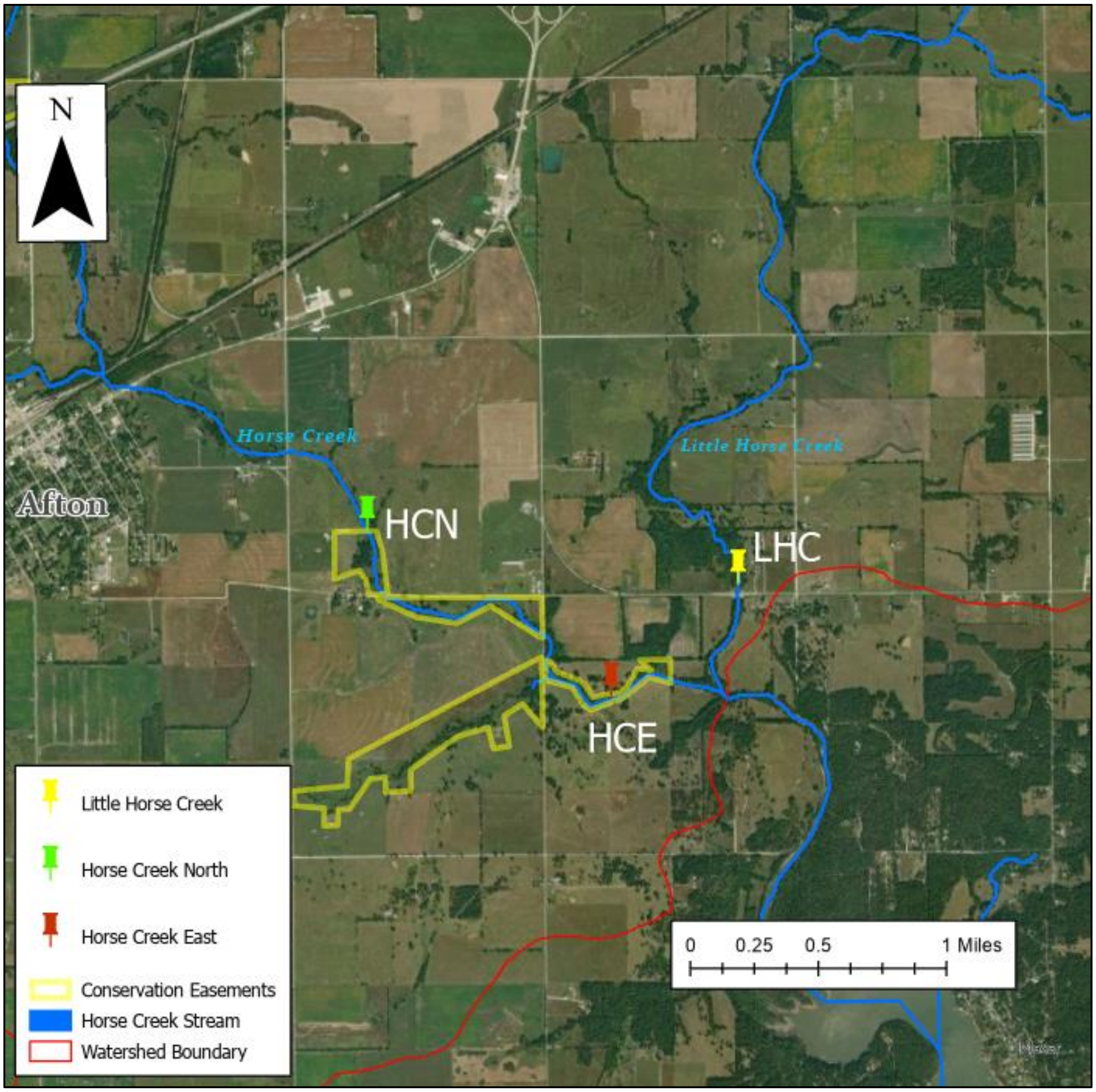


Figure 3. Detail of each of the Horse Creek sample site locations.

From an identified starting point, the investigators worked upstream or downstream to measure a 20-meter section of the stream using a measuring tape. A stake was driven into the substrate to use as a reference point. At this stake, a transect was measured of the width of the channel, from water's edge to water's edge, and was recorded. The measurement of the bankfull width was also recorded. Using a meter stick, the depth of water in the channel was measured at the left ¼, center, and right ¼ (facing downstream) at the transect and recorded. Substrate was evaluated by feeling and visually identifying the size of the benthic material along the perpendicular transect, ranging from silt and clay to boulder-sized substrate. The proportions of all substrate components (totaling 100%) were recorded. The habitat type was evaluated by assessing whether the perpendicular transect is in a riffle, a pool, a run, or was completely dry. In-stream cover was evaluated by estimating the surface area of the stream in the 20-meter section, then estimating the coverage of various structural habitat features (such as large woody debris or emergent aquatic vegetation) within the transect. Nine classes of habitat structures were evaluated and recorded. If the transect was in a run or a riffle, the percent embeddedness was estimated by visually observing the degree to which larger particles have been surrounded by sediment. The percentage of canopy cover over the 20-meter section was estimated by visual observation and recorded. If point bars were present, their presence was noted in the habitat assessment sheet. Evidence of deposition or scouring was also noted. An estimate of bank vegetative cover that protects the bank from erosion along the transect was evaluated. The dominant vegetation class (grasses, trees, or shrubs) that protect the banks from erosion was noted. The percentage of the bank within the transect that was actively eroding was measured and recorded, as well as the height of the eroded bank and its slope. The riparian zone width was estimated by evaluating where the unmanaged (not mowed or plowed) portion of land ends at each transect. Riparian condition was evaluated by visually assessing the dominant land use (forest, grassland, or wetland) as well as the percentage of bare soil visible. Finally, the impact of cattle was evaluated by recording the percentage of land trampled by cattle within a 2-meter strip of the transect, the number of cow pies visible in the 2-meter strip surrounding the transect, the number of cattle trails visible accessing the stream in the entire 20-meter reach, and the width of the visible cattle trails. After each parameter was evaluated, the next 20-meter section of the reach was measured and the evaluation was repeated until 400 meters of stream were assessed.

The results of the habitat assessment were used to inform rapid bioassessment scoring, following the procedures set out in US EPA's Rapid Bioassessment Protocol for Streams and Wadeable Rivers (Barbour et al. 1999). The bioassessment included 13 metrics for stream habitat, including available cover, sediment deposition, bank stability, riparian vegetative width, and flow variability. Following the standard operating procedure, each category was scored on a scale of 0-20, with a score of "20" being optimal and "0" being poor, by comparing the gathered stream metrics to the qualifiers for each score. These parameters were evaluated at each of the 20-meter transects and averaged for an overall score for each of the thirteen rapid bioassessment categories.

2.3. Results and Discussion

2.3.1. Land Use and Land Cover

The land cover dataset revealed the impact of agricultural practices on the Horse Creek watershed. In the Upper Horse Creek watershed (Figure 4, Table 2), over 61% of the watershed was used for pasture and hay, while another 27% was used for crops. Only 2.1% of the watershed was deciduous and mixed forest, almost all of which borders Horse Creek. By comparison, the Fivemile watershed (Figure 5, Table 3) consists of nearly 50% deciduous and mixed forest, 36.6% pasture and hay land use, and no detection of crops.

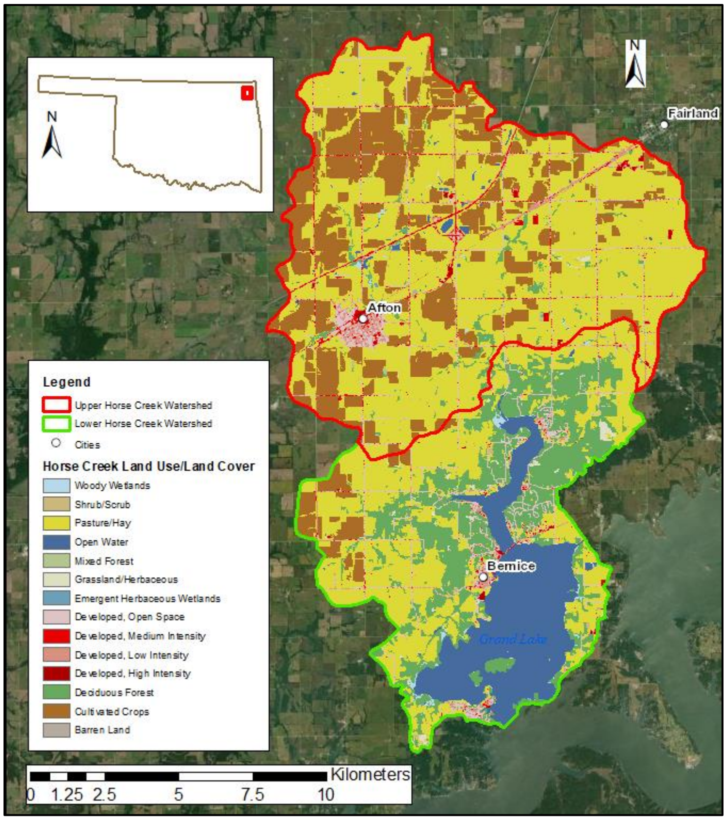


Figure 4. Land use in the Upper Horse Creek and Lower Horse Creek watersheds.

Table 2. Land use in the Upper and Lower Horse Creek Watersheds.

Land Use	**Upper Horse Creek (%)**	**Lower Horse Creek (%)**
Open Water	0.48	16.90
Developed Open Space	2.8	3.33
Developed Low Intensity	3.12	1.20
Developed Medium Intensity	1.84	0.41
Developed High Intensity	0.30	0.10
Barren Land	0.06	0.01
Deciduous Forest	1.99	20.10
Mixed Forest	0.11	0.02
Shrub/Scrub	0.05	0.16
Grassland/Herbaceous	0.14	0.77
Pasture/Hay	61.14	26.74
Cultivated Crops	27.66	29.80
Woody Wetlands	0.16	0.38
Emergent Herbaceous Wetlands	0.08	0.08

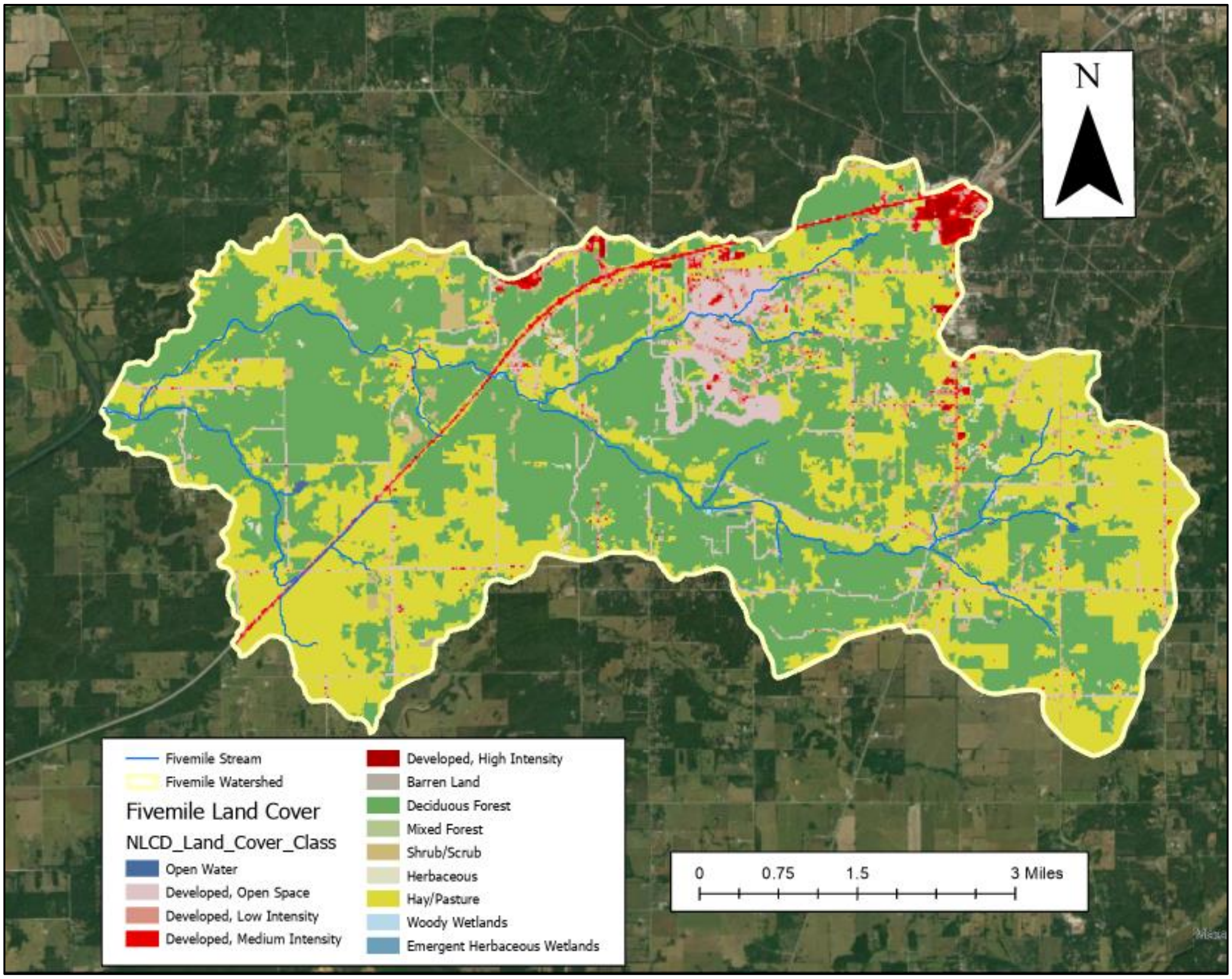


Figure 5. Land use in the Fivemile Creek watershed.

Table 3. Land use in the Fivemile Creek watershed.

Land Use	**Fivemile Creek (%)**
Open Water	0.15
Developed Open Space	7.23
Developed Low Intensity	2.39
Developed Medium Intensity	1.46
Developed High Intensity	0.56
Barren Land	0.07
Deciduous Forest	49.53
Mixed Forest	0.09
Shrub/Scrub	1.28
Grassland/Herbaceous	0.61
Pasture/Hay	36.58
Cultivated Crops	0.00
Woody Wetlands	0.05
Emergent Herbaceous Wetlands	0.00

Both watersheds have a moderate amount of developed land use. In the Horse Creek watershed, much of the open land use is due to residential plots and a small park in the town of Afton. There is not a large degree of impervious surface in this watershed, most of which is present in the main road through Afton as well as a trainyard and the nearby highway. Fivemile watershed is more developed, with a small portion of the city of Joplin, Missouri in the watershed's northeast reach producing a moderate amount of impervious surface. A large area of open developed land, approximately 6.4 km^2, is attributed to a golf course near Loma Linda, Missouri. The watershed also encompasses a portion of a large casino and resort property with a large, impervious parking lot.

2.3.2. Habitat Assessment Scores

Horse Creek North and Little Horse Creek, the two control sites, are not in the riparian conservation easement. Of these, there is no agricultural land use along Little Horse Creek at the survey reach. Horse Creek North, upstream of the conservation easement, is extensively grazed by cattle and reveals the lowest habitat assessment scores (Table 4).

Table 4. Habitat Assessment scores at each of the study sites.

Habitat Parameter	Treatment (HCE)	Control 1 (HCN)	Control 2 (LHC)	Reference (5MI)
Epifaunal Substrate/Available Cover	8.5	3.2	9	4.4
Embeddedness	18.8	14.5	18.3	18.5
Pool Substrate Characterization	8.7	14	7.4	17
Velocity/Depth	15	4	13	18
Pool Variability	10	8	10	17
Sediment Deposition	13.2	18	14.6	10.5
Channel Flow Status	10	15	9.1	7.6
Channel Alteration	18	18	19	15
Frequency of Riffles	8	2	10	14
Channel Sinuosity	7	3	7	7
Bank Stability	10.4	11.5	11.7	5.7
Bank Vegetative Protection	11.75	9.4	9.27	4.6
Riparian Vegetative Zone Width	15.9	0.9	20	20
Total Score (/260)	**155.25**	**121.5**	**158.37**	**159.3**

The reach is severely degraded in terms of epifaunal substrate and available cover (score 3.2/20), velocity/depth regime (score 4/20), the frequency of riffles (score 2/20), sinuosity (score 3/20), and riparian vegetative zone width (score 0.9/20). As variety and abundance of cover decreases, fish and macroinvertebrate populations and diversity are predicted to decrease, and the potential for those populations to recover following disturbances is also predicted to decrease (Barbour et al. 1999). The lack of refugia for fish and other aquatic animals means there is a lack of cover from predators, little area to avoid high water temperatures, and area to rest from high velocity water. Similarly, a lack of velocity and depth regime changes indicates lack of habitat for fish that prefer different regimes, such as deep-slow or fast-shallow water. Riffles provide support for fish and benthic invertebrate life by increasing dissolved oxygen in the stream reach. Lack of riffles predicts low dissolved oxygen and a lack of variety of fish species that prefer riffle habitats (Matthews 1990). Sinuosity refers to the ratio of channel length to direct down-valley length. The curves and meanders of a stream help to absorb and dissipate stream energy (Barbour et al. 1999). A high degree of sinuosity provides for diverse habitat and resilience to storm surges; conversely, a lack of sinuosity predicts poor resilience to erosion and decreased recovery time following a disturbance. The first control reach at Horse Creek North is extensively grazed by cattle and, as such, exhibits almost no riparian vegetative width, providing almost no buffering to erosion or runoff (Figure 6). This reach was also the only one of the four assessed to show direct impacts of cattle access, including increased erosion due to cattle trails and trampling of riparian vegetation.

Figure 6. Control site 1, Horse Creek North, upstream of the conservation easement. Imagery taken August 2022.

The second control site, Little Horse Creek, exhibits a completely different structure despite its proximity within the same watershed. The reach evaluated is not used for agricultural purposes due to a large cliff on the eastern side of the reach and a bottomland hardwood forest on the western side (Figure 7).

Figure 7. Control site 2, Little Horse Creek. Imagery taken July 2022.

The habitat scores here were higher than the Horse Creek North site, with no metrics falling into the "poor" range of scores. The greatest impairments to this system lie in the lack of variability of substrate and available cover, as well as poor scores for channel flow status. Substrates in this reach were completely dominated by bedrock, boulder-sized substrate, and large cobble. The clean bedrock bottoms of this reach provide little habitat for fish or macroinvertebrates, and the nearly total lack of submerged or aquatic vegetation provides no refuge from larger predators. Available cover was dominated by bedrock ledges, which did not provide a large range of habitat types for different aquatic organisms. Channel flow status refers to the degree to which the channel is filled with water. When water does not cover much of the streambed, the amount of suitable substrate for aquatic organisms is limited (Barbour et al. 1999). Due to the width of the channel on the western bank, the stream regularly filled less than 75% of the available channel width at baseflow, and riffle substrates were mostly exposed, decreasing the availability of cover for benthic macroinvertebrates.

The site at Horse Creek East, which is the treatment site, is in the downstream portion of the conservation easement. Scores at this reach generally fell into "good" or "fair" categories, with major impairments due to relatively low bank stability, poor pool substrate, and channel flow status. Although the bank vegetation scores are the highest of any of the four sites assessed (11.75/20), indicating the presence of rooted plants to help stabilize the streambank, the bank stability is fairly low, and erosion is evident. The sediment in the banks at the Horse Creek East treatment reach are fine, consisting of mostly clay and silt. Although the cattle exclusion fences are allowing vegetation to re-colonize the riparian zone, many of the transects in the reach were dominantly covered in grasses, with a handful of large trees (Figure 8). In time, these grasses are likely to give way to shrubs and more trees, but have not had enough time to stabilize the banks of Horse Creek in this reach yet. The benthos of the stream reach here is dominated by bedrock, which provides poor habitat structure and diversity. In-stream cover was present, but is patchy throughout the reach. Submerged and emerged aquatic vegetation were present, but only in slow, shallow runs and pools. Riffles were more present than in Horse Creek North, with two large riffle sections in the reach, providing increased dissolved oxygen to the stream.

Figure 8. Horse Creek East riparian area, part of the conservation easement. Cattle exclusion fences have been installed on both sides of the streambank. Image credit: GRDA.

Fivemile Creek scored relatively well, with a major impairment (score 4.6/20) due to lack of streambank vegetation and a correspondingly low bank stability (score 5.7/20), as well as lack of epifaunal substrate or available cover (score 4.4/20). The impacts of flashy floods were immediately evident at Fivemile, with streambanks four meters tall stripped bare of any vegetation at some transects. The width of the channel between the banks was also very wide for its baseflow – the average width of the water at baseflow in this reach is 13.3 meters, and the average bankfull width is 32.6 meters (Figure 9). This low ratio of bankfull width to channel width caused Fivemile Creek to score the poorest of any of the reaches assessed for the channel flow status category.

Figure 9. The reference site, Fivemile Creek, facing upstream from S680 Road. Image taken July 2022.

The streambanks have greater stability in the northern side of the creek, where a small forested patch was present along a majority of the reach, and erosion was greatest at the southern side of the reach. It is likely that the scouring from these flood events also contributed to the lack of available cover in the stream. Piles of logs were evident in some of the gravel bars along the reach, but the aquatic habitat itself was largely stripped bare of submerged or emergent vegetation.

The Fivemile Creek habitat assessment scored highly for velocity/depth regime, frequency of riffles, pool variability, and riparian zone vegetated width. Different combinations of flow regimes (fast-shallow to slow-deep) were present along the reach. The relative frequency of riffles indicated a high degree of oxygenation. Pools were more varied than in any of the Horse Creek sites, with some of the pools over 1.5 meters deep at baseflow conditions. The substrate at this reach was more varied than any of the Horse Creek sites as well, with less influence of bedrock and a higher degree of gravel and cobble-sized substrate. The riparian vegetated zone was not influenced by anthropogenic impacts, either from cattle or from mowing hay, within 15 meters of the stream banks. Scores for all habitat assessment metrics may be found in Appendix A.

2.4. Conclusions

The evaluation of the Horse Creek and Fivemile Creek watersheds described useful structural details in the characterization of each of these watersheds. Land use and land cover evaluations revealed a high degree of agricultural impacts to the Horse Creek watershed and a relatively low degree of agricultural impact in the Fivemile Creek watershed. Three reaches in the Horse Creek watershed were evaluated for in-stream and riparian habitat, and each reveals different habitat structures and impairments. The first control site at Horse Creek North, which is not in a conservation easement and exhibits a high degree of cattle grazing, scored the lowest on its habitat assessment. The second control site, Little Horse Creek, had a healthy riparian zone but lacked substrate variability. The conservation easement treatment site, Horse Creek East, scored well in its habitat assessment, with impairments due to lack of substrate variability and a high degree of erosion. The reference watershed at Fivemile Creek exhibited high scores for stream variability, but the impact of high flow events impairs the reach in terms of erosion and riparian vegetative cover.

References

Arango, J.G. Use of Small Unoccupied Aerial System Multispectral Imagery to Address Optical and Non-Optical Water Quality Parameters in Watershed Restoration. Ph.D. Dissertation, University of Oklahoma, Norman, OK, 2020.

Barbour, M.T.; Gerritsen, J.; Snyder, B.D.; Stribling, J.B. Rapid Bioassessment Protocols for use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. EPA 841-B-99-002 **1999**. https://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-1164.pdf

Bláha, L.; Babica, P.; Maršálek, B. Toxins produced in cyanobacterial water blooms – toxicity and risk. *Interdisciplinary Toxicology* **2009**, 2(2), 36-41. DOI: 10.2478/v10102-009-0006-2.

Bodie, J.R. Stream and Riparian Management for Freshwater Turtles. *J. Environ. Manag.* **2001**, *62*, 443-455. DOI: 10.1006/jema.2001.0454

Boyer, T.A.; Daniels, B.; Melstrom, R.T. *Algal Blooms in Oklahoma: Economic Impacts*; AGEC-1063; Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources, Oklahoma State University. https://extension.okstate.edu/fact-sheets/algal-blooms-in-oklahoma-economic-impacts.html (accessed 2021-07-21).

Doehring, K.; Clapcott, J.E.; Young, R.G. Assessing the Functional Response to Streamside Fencing of Pastoral Waikato Streams, New Zealand. *Water* **2019**, *11 (1347)*, 1-22. DOI: 10.3390/w11071347

Garbrecht, J.; Martz, L.W. Digital Elevation Model Issues in Water Resources Modeling. *Hydrologic and Hydraulic Modeling Support with Geographic Information Systems, ESRI Press*, **2000**, 1-28. https://proceedings.esri.com/library/userconf/proc99/proceed/papers/pap866/p866.htm

Grand River Dam Authority (GRDA). Final Draft: Shoreline Management Plan. *Pensacola Project FERC No. 1494*, last revised June 2008. https://digitalprairie.ok.gov/digital/collection/stgovpub/id/6092/ (accessed 2021-07-13).

Gregory, S.V.; Swanson, F.J.; McKee, W.A.; Cummins, K.W. An Ecosystem Perspective of Riparian Zones. *Bioscience* **1991**, *41 (8)*, 540-551. DOI: 10.2307/1311607

Kansas Forest Service, Kansas State University. *Riparian Buffers, Best Management Practices: Fencing* [MF-2752], last revised August 2006. https://www.kansasforests.org/streamside_forestry/streamside_docs/Fencing.pdf (accessed 2021-08-11)

Krehbiel, R. GRDA Expands Conservation Project to Grand Lake. *Tulsa World* (Tulsa, OK). September 9, 2020 updated October 17, 2020. https://tulsaworld.com/news/state-and-regional/govt-and-politics/grda-expands-conservation-project-to-grand-lake/article_b53d1f3e-f2d0-11ea-92f3-1f34226ba8aa.html (accessed 2021-06-29).

Line, D.E.; Harman, W.A.; Jennings, G.D.; Thompson, E.J.; Osmond, D.L. Nonpoint-Source Pollutant Load Reductions Associated with Livestock Exclusion. *J. Environ. Qual.* **2000**, *29*, 1882-1890. DOI: 10.2134/JEQ2000.00472425002900060022X

Matthews, W.J. Spatial and Temporal Variation in Fishes of Riffle Habitats: A Comparison of Analytical Approaches for the Roanoke River. *American Midland Naturalism* **1990**, 124 (1), 31-45. DOI: 10.2307/2426077

Multi-Resolution Land Characteristics (MRLC) Consortium. **2019**. https://www.mrlc.gov/

Mason, A.M.; Triplett, J. Controlling Environmental Crisis Messages in Uncontrollable Media Environments: The 2011 Case of Blue-Green Algae on Grand Lake O' the Cherokees, OK. In *Communicating Climate-Change and Natural Hazard Risk and Cultivating Resistance*; Springer, 2016; pp. 189-204.

Morrison, J.M.; Baker, K.D.; Zamor, R.M.; Nikolai, S.J.; Elshahed, M.S.; Youssef, N.H. Spatiotemporal Analysis of Microbial Community Dynamics During Seasonal Stratification Events in a Freshwater Lake (Grand Lake, OK, USA). *PLoS One* **2017**, *12 (5)*, 1-29. DOI: 10.1371/journal.pone.0177488

Nikolai, S.J.; Dzialowski, A.R. Effects of Internal Phosphorus Loading on Nutrient Limitation in a Eutrophic Reservoir. *Limnologica* **2014**, *49*, 33-41. DOI: 10.1016/j.limno.2014.08.005

O'Callaghan, P.; Kelly-Quinn, M.; Jennings, E.; Antunes, P.; O'Sullivan, M.; Fenton, O.; Huallachain, D.O. The Environmental Impact of Cattle Access to Watercourses: A Review. *J. Environ. Qual.* **2018**, *48*, 340-351. DOI: 10.2134/jeq2018.04.0167

Oklahoma Climatological Survey. *Ottawa County Climate Summary*. https://climate.ok.gov/county_climate/Products/QuickFacts/ottawa.pdf (accessed 2021-07-11).

Oklahoma Conservation Commission. Habitat Assessment: Oklahoma Conservation Commission Water Quality Division Standard Operating Procedure. **2006**. https://www.bluethumbok.com/uploads/2/7/3/3/27333921/habitat_sop_2006.pdf

Oklahoma Conservation Commission. Know Your Stream: Rotating Basin Site Summary Ottawa County, Ozark Highlands Level 3 Ecoregion. **2008**. https://okmaps.org/OGI/wq/SiteSumAll_C2/SiteSumottawa2.pdf

Oklahoma Water Resources Board, Oklahoma Water Watch, Grand Lake Association Chapter. *Draft 1993-2001 Data Summary*; Oklahoma City, OK, 2001.

Parece, T.; Campbell, J.B. Land Use/Land Cover Monitoring and Geospatial Technologies: An Overview. *The Handbook of Environmental Chemistry*, vol. 33, **2015**, Chapter 2. https://doi-org.ezproxy.lib.ou.edu/10.1007/978-3-319-14212-8_1

Parsons, C.T.; Momont, P.A.; Delcurto, T.; McInnis, M.; Porath, M.L. Cattle Distribution Patterns and Vegetations Use in Mountain Riparian Areas. *J. Range Manage.* **2003**, *56*, 334-341. DOI: 10.2307/4004036

Swanson, S.; Wyman, S.; Evans, C. Practical Grazing Management to Maintain or Restore Riparian Functions and Values on Rangelands. *J. Rangel. App.* **2015**, *2*, 1-28. ISSN: 2331-5512.

U.S. Environmental Protection Agency, 2013, Level III ecoregions of the continental United States: Corvallis, Oregon, U.S. EPA – National Health and Environmental Effects Research Laboratory, map scale 1:7,500,000, https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states.

Health and Environmental Effects Research Laboratory, map scale 1:7,500,000, https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states.

United States Geological Survey (USGS). Watershed Boundary Dataset. **2017**. https://www.usgs.gov/national-hydrography/watershed-boundary-dataset

United States Geological Survey (USGS). USGS 1/3 Arc Second n37w095 20210623. **2021**. https://www.sciencebase.gov/catalog/item/60d56317d34ef0ccfc0c84bb

Vidon, P.G.; Welsh, M.K.; Hassanzadeh, Y.T. Twenty Years of Riparian Zone Research (1997-2017): Where to Next? *J. Environ. Qual.* **2018**, *48*, 248-260. DOI: 10.2134/jeq2018.01.0009

Zhang, W.; Montgomery, D.R. Digital Elevation Model Grid Size, Landscape Representation, and Hydrologic Simulations. *Water Resour. Res.* **1994**, *30(4)*, *1019-1028*. DOI: 10.1029/93WR03553

Chapter 3 - Biota in the Horse Creek Watershed of the Grand Lake o' the Cherokees, Oklahoma

Abstract: In agriculturally dominated watersheds such as the Horse Creek watershed, loss of riparian habitat has been identified as a major contributor to water quality degradation. Previous studies have monitored physicochemical water quality data on a monthly basis. However, no studies of in-stream or riparian biota had previously been conducted to determine if conservation efforts had an impact on aquatic life. Fish and macroinvertebrate assemblage data were collected in late summer 2022 and were compared to land use and habitat assessment metrics to quantify the impact of riparian vegetation protection, as well as compared to reference conditions. Results indicated that both fish and macroinvertebrate assemblage metrics respond to land use, with positive correlations to riparian vegetative zone width and stream flow variability, and negative correlations to developed land use in the watershed. These data highlight the importance of riparian vegetative zones in the improvement of biotic assemblages in the stream. Remote sensing was also conducted using a small Unoccupied Aerial System (sUAS) to collect high-definition multispectral imagery within the conservation easement areas. The Normalized Difference Vegetation Index (NDVI) was used to calculate riparian vegetation photosynthetic vigor within the conservation easements and compared to data collected in 2020. NDVI improved at two of the sites studied by approximately 3%, but decreased at a third site by approximately 5%, likely due to exceptional drought conditions along the study reach. Digital surface models collected by sUAS were used to estimate aboveground biomass, and indicated an approximate 2% increase in vegetation volume at all three sites, indicating that the cattle exclusion fences are succeeding in allowing vegetation to re-establish.

Keywords: NDVI, Fish Assemblage, Macroinvertebrate Assemblage, Land Use, Land Cover, Habitat Assessment

3.1. Introduction

3.1.1. Fish and Macroinvertebrate Assemblages

Fish assemblages are sensitive indicators of physical and chemical habitat degradation, water contamination, and ecosystem productivity (EPA 2022). The richness and diversity of fish species in rivers and lakes indicate the relative condition of the functional and structural characteristics of the habitat (Gafny et al. 2000). They are affected by changes in pH, temperature, dissolved oxygen, and other physical and chemical components in water (Barrella & Pitrere 2003; Jeffree et al. 2001). The distribution and composition of fish assemblages are largely driven by flow variability (Bice et al. 2014); abiotic factors, such as dissolved oxygen (Winemiller et al. 2000); and biotic factors, such as vegetation cover (Weaver et al. 1997). These factors affect fish structure by influencing life history processes including migration, spawning, and recruitment (King et al. 2009).

The analysis of macroinvertebrate community structures is a common tool to assess stream health. Benthic macroinvertebrates offer many advantages in biomonitoring. They are found in almost all aquatic habitats (Lenat et al. 1980) and the large number of species that can be found in streams offers a spectrum of responses to environmental stressors (Abel 1996). Their abundance and distribution throughout stream systems and sessile nature allow for spatial and temporal analysis of pollutants or disturbances (Penny 1985; Hellawell 1986). Sampling and analysis can be accomplished quickly and inexpensively, and biotic diversity indices have been developed and are widely used in biomonitoring applications (Rosenberg and Resh 1993).

For this study, fish and macroinvertebrate assemblages were collected at three sites (control: Horse Creek North, treatment: Horse Creek East, reference: Fivemile Creek) in late summer of 2022. Various biotic metrics, such as Shannon-Wiener diversity, species richness and evenness, and macroinvertebrate Hilsenhoff Biotic Index, were calculated for each site, and compared to sub-watershed land use and habitat metrics. The hypothesis for this portion of the study is that fish and macroinvertebrate community assemblage metrics are greatest at Fivemile Creek because of superior habitat assessment metrics and decreased anthropogenic land use in the watershed.

3.1.2. Riparian vegetation recovery using sUAS

The Normalized Difference Vegetation Index (NDVI) was developed for satellite imagery analysis of vegetation. NDVI works by assessing the reflectance of near-infrared (NIR) and red light from vegetation (Figure 10). Healthy, vigorous plants absorb a large fraction of red light and reflect and large fraction of near-infrared light, whereas stressed plants reflect a greater portion of red light and reflect less NIR radiation (Huang et al. 2021).

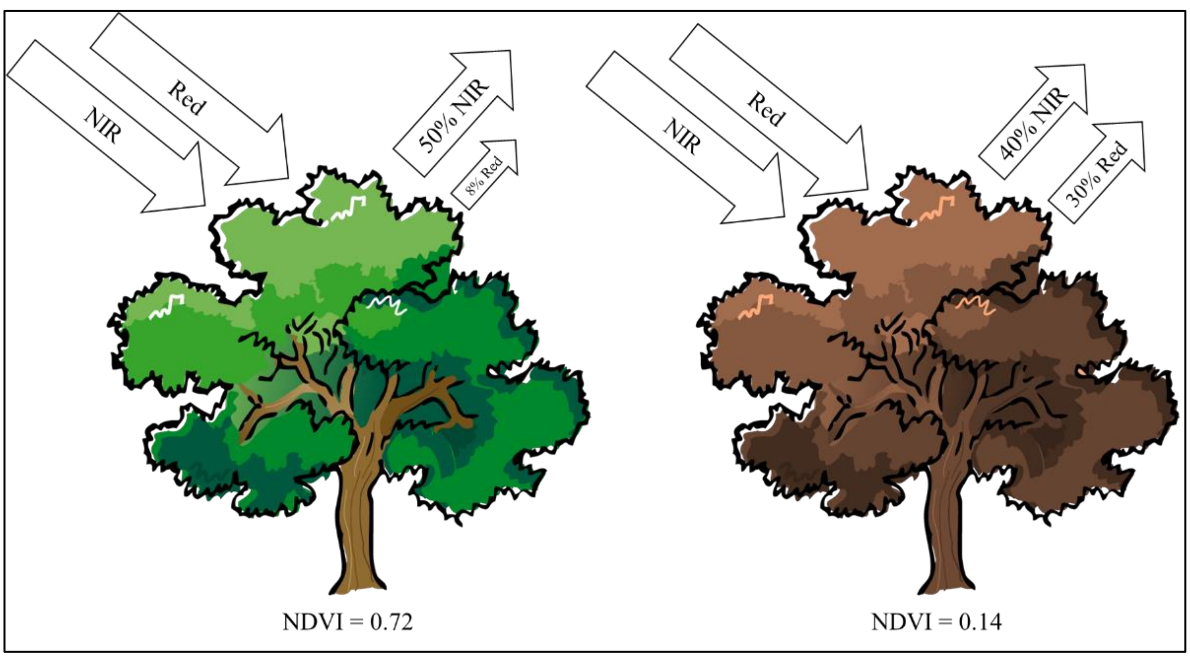


Figure 10. Visualization of NDVI on healthy (left) and stressed (right) vegetation.

This relationship is represented by the equation (Equation 1):

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Equation 1. Calculation of NDVI from NIR and Red reflectance values.

where “NIR” and “Red” represent the fraction of those wavelengths of light reflected from an object. In remote sensing, these values are captured for all pixels of an image captured by a multispectral sensor and can be manipulated in GIS software to calculate NDVI from rasters. The method is widely used as an analytical tool due to a strong correlation with photosynthesis and primary vegetation production (Nagler et al. 2004). Recent advances in sUAS technology have allowed the capture of multispectral imagery and the evaluation of NDVI (Liu et al. 2019). These missions have the capability to evaluate an area quickly, inexpensively, and at a far greater resolution than satellite imagery. The hypothesis for this portion of the study is that study sites fenced in conservation easements will show increases in NDVI and canopy volume (as a proxy for aboveground biomass) due to decreased stress from livestock grazing.

3.2. Materials and Methods

3.2.1. Fish and Macroinvertebrate Assemblages

Fish and macroinvertebrate surveys were conducted in late summer 2022, according to OCC SOPs. In summary, a 15-foot seine with a 1/8” mesh was used to capture fish at all three locations. Each stream was sampled for a distance of 400-m upstream of each sampling area, in the same reaches that were used for the habitat assessments. As fish were hauled, they were identified in the field and counted before returning them to the stream. The first of each species of fish captured was preserved in a jar of 10% formalin. Fish returned to the laboratory were identified using reference samples, visual guides, and dichotomous keys. The count of each species of fish at each site was recorded.

Fish assemblages were assessed for species richness, total count, Shannon-Wiener Species Diversity Index, and Shannon Equitability Index ("evenness"). Richness refers to the number of species within the sampling reach. The total count is the sum of all fish collected at each site. The Shannon-Wiener Species Diversity Index (H) is used to calculate the diversity of species in a community and is calculated as (Equation 2):

$$H = -\Sigma p_i \cdot \ln{(p_i)}$$

Equation 2. Calculation of Shannon-Wiener Species Diversity Index.

where p_i is the proportion of the entire community made up of species *i* (Statology 2021). The higher the value of H, the higher the diversity in that community. The Shannon-Wiener Diversity Index is used to calculate the Shannon Equitability Index (E_H), which is used to measure the evenness of species in a community and is calculated by dividing the Shannon-Wiener Diversity Index by the natural log of species richness (Equation 3; Statology 2021):

$$E_H = \frac{H}{\ln{(S)}}$$

Equation 3. Calculation of species evenness.

Macroinvertebrate assemblages were collected in rocky riffles as near to each sample location as possible. A 1-m^2 kick net with #30 nylon mesh was placed facing downstream in each riffle section, so that organisms dislodged would be swept into the net by the current. Organisms were brushed off of rocky substrate in the 1-m^2 area in front of the kick net by hand, then the substrate was kicked to agitate and dislodge organisms. The organisms caught by sampling were transferred to a mason jar and preserved in 100% ethanol for identification in the laboratory. Samples were decanted through a #30 sieve and gently rinsed to remove silt and clay, as well as to manually remove large pieces of leaves, bark, and rocks. The samples were evenly spread into a rectangular pan with a 28-square grid for picking. A random number generator was used to select individual cells, and all macroinvertebrates in the chosen square were picked for identification. This process was repeated until 200 macroinvertebrates were picked. At two of the sites, 200 organisms were not present in the sample, so picking continued until all organisms were removed. Macroinvertebrates were identified with the use of visual guides and dichotomous keys to determine their taxonomic order and family. The count of each family of macroinvertebrate was recorded for each site.

Macroinvertebrate assemblages were assessed for species richness, Hilsenhoff Biotic Index (HBI), and Ephemeroptera-Plecoptera-Trichoptera (EPT) Index. Species richness refers to the number of unique species identified at each site. The Hilsenhoff Biotic Index is used to estimate water quality based on the pollution tolerance the community in a sampled area, weighted by the relative abundance of each taxonomic group. Taxa pollution sensitivity scores from 0 (highly sensitive) to 10 (extremely pollution-tolerant) (Hilsenhoff 1977). HBI is calculated as (Equation 4):

$$HBI = \frac{\Sigma(n_i a_i)}{N}$$

Equation 4. Calculation of Hilsenhoff Biotic Index.

where n is the number of specimens in each taxon, a is the pollution tolerance value of that taxon as calculated by Hilsenhoff (Hilsenhoff 1982), and N is the total number of specimens in the sample. The resulting score provides a categorical representation of water quality (Table 5).

Table 5. Evaluation of water quality using HBI values (Hilsenhoff 1987).

Biotic Index	Water Quality
0.00 – 3.50	Excellent
3.51 – 4.50	Very Good
4.51 – 5.50	Good
5.51 – 6.50	Fair
6.51 – 7.50	Fairly Poor
7.51 – 8.50	Poor
8.51 – 10.00	Very Poor

The EPT Index refers to the number of Ephemeroptera (mayflies), Trichoptera (caddisflies), and Plecoptera (stoneflies) orders caught at each site. These orders are generally sensitive to pollution in freshwater systems (Haney 2013). The EPT Index can be calculated as a percentage of EPT taxa to the total number of taxa found (Equation 5) and predicts that EPT taxa richness will decrease with decreasing water quality (Blattenberger et al. 2000).

$$EPT\ Index = \frac{Total\ EPT\ Taxa}{Total\ Taxa\ Found} \cdot 100\%$$

Equation 5. Calculation of the EPT index.

3.2.2. sUAS Flights and NDVI

All sUAS missions were flown with an Aerial Technologies International (ATI) "AgBot" platform, equipped with a MicaSense Red Edge multispectral sensor. Before each flight, the mission parameters and flight area were designed in Mission Planner software, with flight patterns following the conservation easement areas of interest. At each flight location, the AgBot was unpackaged and prepared according to manufacturer specifications. The AgBot was connected to the field laptop containing Mission Planner software using a wireless link, and the flight parameters were uploaded to the sUAS. Before launching the sUAS, the pilot captured an image of a calibrated reflectance panel, which was used to calibrate imagery in processing. Once the pilot took control of the AgBot, the platform was launched and the mission proceeded until all images were captured. This process was repeated at each flight area.

Once all images had been captured, the data were processed in Pix4DMapper software (Pix4D 2022). Images from each flight were uploaded to the software, and the image of the calibrated reflectance panel was identified to radiometrically correct the reflectance values captured by the multispectral sensor. The software generated a GeoTIFF file by layering the mosaic of images taken by the sUAS for each band (red, green, blue, near-infrared, red edge) captured by the sensor. To combine these images into one multi-band image processable in GIS software, OSGeo4W software was used to build a virtual dataset.

In GIS software, the virtual raster file containing the five multispectral bands was visualized and used for geoprocessing. The Raster Math toolset in ArcGIS Pro was used to calculate NDVI. This process was repeated for each site at each area of interest. To evaluate the vegetation recovery and extent, the NDVI values captured in late summer 2022 were compared to NDVI values captured at the same sites in late summer of 2020. Using the Raster Math toolset and subtracting the 2022 data from previous years, areas of NDVI Increase and decrease were identified (Figure 12).

A similar process was used to evaluate increases in canopy volume. Digital surface models (DSMs) were generated alongside the imagery process described above. In ArcGIS Pro, DSM files were applied to each of the flight areas to generate a three-dimensional representation of the conservation easement surface. Canopy volumes were calculated by performing a Surface Volume calculation on all points higher than the reference plane (ground surface). This volume was calculated for the 2020 and 2022 sUAS flights, and the difference between the two volumes was calculated as a percent change (Figure 13).

3.2.3. Data Analyses

Data were analyzed using Bayesian inference, a statistical tool that is increasingly being used in the field of ecology. Bayes' theorem generates a probability distribution that provides a direct measure of the degree of belief that can be placed on models, hypotheses, or parameter estimates by providing a quantitative measure of the probability of a hypothesis being true in the light of available data (Ellison 2004). Bayesian models are used in population studies (Cummings et al. 2002). Conditional probabilities calculated using Bayes' Theorem are used extensively in dynamic models of population behavior (Valone and Brown 1989) and have been used in estimation of species richness (Fleishman et al. 2003) and land-use history and community reconstruction (Platt et al. 2002).

Bayesian methods calculate the probability of a value of a parameter given the observed data (Wade 2000). Since the distribution of the parameter is unknown, it is given a "prior" distribution in which any positive value is equally likely. The "posterior" distribution represents a statement about how probable different values of the parameter are in light of the data and data distribution. In short, the score for Bayes' Factor can be defined as (Equation 6):

$$\frac{likelihood\ of\ data\ given\ H_A}{likelihood\ of\ data\ given\ H_0} = \frac{P(D|H_A)}{P(D|H_0)}$$

Equation 6. Bayes' Factor score calculation.

Where H_A and H_0 represent the alternative and null hypotheses, respectively, and the probability (P) of the distribution (D) given the alternative and null hypotheses. For the purposes of this study, Bayes' Factor and Pearson correlation were assessed using IBM SPSS software. Fish and macroinvertebrate community metrics (Shannon-Wiener diversity, species richness, species evenness, macroinvertebrate Hilsenhoff Biotic Index) were compared to watershed land use and land cover metrics and habitat assessment data. The model was processed using the Pearson Correlation tool. The Bayesian 95% credible interval was used (Hespanhol et al. 2018), and 10,000 samples were simulated for posterior distribution, with the assumption that the prior distribution was uniform.

Bayes' factor describes the likelihood that the null (H_0) hypothesis is more strongly supported by the data than the alternative (H_A) hypothesis (IBM 2022). In these tests, the null hypothesis was that the independent variable (land use or habitat metrics) did not have an impact on the dependent variables (fish and macroinvertebrate community metrics). The alternative hypothesis in each case was that the independent variable did have an impact on the dependent variable. Bayes' factor was used on a categorical scale, where larger factors supported the null hypothesis and smaller factors supported the alternative hypothesis (Table 6).

Table 6. Bayesian thresholds to define significance of evidence. Adapted from IBM (2022).

Bayes' Factor	**Evidence Category**
> 100	Extreme evidence for H_0
30-100	Very strong evidence for H_0
10-30	Strong evidence for H_0
3-10	Moderate evidence for H_0
1-3	Anecdotal evidence for H_0
1	No evidence
0.33 – 1	Anecdotal evidence for H_A
0.10 – 0.33	Moderate evidence for H_A
0.03 – 0.10	Strong evidence for H_A
0.01-0.03	Very strong evidence for H_A
< 0.01	Extreme evidence for H_A

Pearson correlation is the measure of linear correlation between two sets of data. It is the ratio between the covariance of two variables and the product of their standard deviations, producing a standardized covariance with the result between -1 and 1, given by (Equation 7). Generally, the magnitude of the Pearson correlation coefficient can be used to describe the relationships between populations and community metrics, and the direction of the correlation describes whether or not the relationship is positive or negative (Vorsino et al. 2014).

$$\boldsymbol{r = \frac{\Sigma(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\Sigma(x_i - \overline{x})^2(y_i - \overline{y})^2}}}$$

Equation 7. Calculation of the Pearson correlation coefficient.

Where r is the correlation coefficient, x_i represents the values of the x-variable in a sample, $\bar{x}$ represents the mean of the x variable values, y_i represents the values of the y-variable in a sample, and $\bar{y}$ represents the mean of the values of the y-variable.

3.3. Results and Discussion

3.3.1. Fish Assemblages

Fish and macroinvertebrate metrics were greatest at the reference site, followed by the treatment site, then Control site 1. Control site 2 (Little Horse Creek) was excluded from assessment due to drought conditions. Fish and macroinvertebrate taxonomic diversity is indicative of resilience to community and environmental change (Santora et al. 2021), habitat heterogeneity (Heino et al. 2003), and water quality (Soldner et al. 2004). The reference site, Fivemile Creek, had the highest fish species richness (S = 12), species evenness (E_H = 0.785), and highest Shannon-Wiener Diversity Index score (H = 2.07; Table 7). *Etheostoma* "darter" species were present at the reference site, but not present at the control or treatment sites. The presence of darters indicates appropriate water quality and stream habitat due to their low tolerance for siltation and pollution (Shaw 2019).

Table 7. Species of fish caught at the reference site Fivemile Creek site near Quapaw, Oklahoma.

Species Name	Common Name	Count	Proportion
Labidesthes sicculus	Brook silverside	46	0.261
Gambusia affinis	Mosquitofish	41	0.233
Notropis boops	Bigeye shiner	31	0.176
Fundulus catenatus	Northern studfish	12	0.068
Luxilus cornutus	Common shiner	10	0.057
Fundulus notatus	Blackstripe topminnow	10	0.057
Etheostoma spp.	Darter spp.	9	0.051
Micropterus salmoides	Largemouth bass	6	0.034
Lepomis macrochirus	Bluegill	6	0.034
Noturus exilis	Slender madtom	2	0.011
Lepomis megalotis	Longear sunfish	2	0.011
Semotilus atromaculatus	Creek chub	1	0.006

The Control 1 site, Horse Creek North, had the highest total count of fish (n = 400), but many were juvenile bluegill less than 2 inches long (Table 8). The control site scored poorly for species richness (S = 8), species evenness (E_H = 0.551), and Shannon-Wiener Diversity (H = 1.15).

Table 8. Species of fish caught at the Control 1 portion of Horse Creek.

Species Name	Common Name	Count	Proportion
Lepomis macrochirus	Bluegill	175	0.438
Fundulus notatus	Blackstripe topminnow	172	0.43
Lepomis cyanellus	Green sunfish	33	0.83
Labidesthes sicculus	Brook silverside	10	0.025
Gambusia affinis	Mosquitofish	5	0.013
Lepomis microlophus	Redear sunfish	2	0.005
Semilotus atromaculatus	Creek chub	2	0.005
Pomoxis annularis	White crappie	1	0.003

The treatment site, Horse Creek East, scored higher than the control site but lower than the reference site for species richness (S = 10), species evenness (E_H = 0.703), and Shannon-Wiener Diversity (H = 1.62; Table 9).

Table 9. Species of fish caught in the treatment portion of Horse Creek.

Species Name	Common Name	Count	Proportion
Gambusia affinis	Mosquitofish	104	0.378
Fundulus notatus	Blackstripe topminnow	67	0.244
Lepomis macrochirus	Bluegill	58	0.211
Labidesthes sicculus	Brook silverside	18	0.065
Micropterus salmoides	Largemouth bass	9	0.033
Lepomis microlophus	Redear sunfish	7	0.025
Lepomis humilis	Orange-spotted sunfish	4	0.015
Lepomis cyanellus	Green sunfish	3	0.011
Semilotus atromaculatus	Creek chub	3	0.011
Ictaluris punctatus	Channel catfish	2	0.007

Fish Shannon-Wiener diversity metrics were best predicted by "Developed, Low Intensity" and "Developed, Medium Intensity" land use characteristics, as well as "Velocity/Depth Regime" and "Riparian Vegetative Zone Width" habitat metrics. The negative correlation coefficients between fish diversity and developed land use suggested that as urban land development in a watershed increases, fish diversity decreases. Conversely, fish diversity was predicted to improve by the positive correlation with "velocity/depth regime" and "riparian vegetative zone width". Bayes' factors for fish diversity for these metrics fell into the 0.1-0.33 range, making the relationships between all of these variables moderately strong.

Fish assemblage species richness was best estimated by pool variability. Pool variability was scored by the presence of various flow regimes in stream pool areas (fast-deep, fast-shallow, slow-deep, slow-shallow). Each of these provides refugia and areas to rest from faster-moving runs and riffles, and different regimes may be favored by different species. Where species richness was highest (Fivemile Creek), pool variability scored highest (17/20, Table 4). Similarly, fish species evenness was best predicted by the presence of epifaunal substrate and available cover (Bayes' factor = 0.306).

3.3.2. Macroinvertebrate Assemblages

Of the three sites assessed, the reference site at Fivemile Creek scored the highest for species richness (S = 18), Shannon-Wiener Diversity (H = 1.86), and scored the lowest for HBI (HBI = 3.9). The reference site was also the only site assessed that had EPT taxa present, with eight taxa identified and an % EPT taxa score of 44.4. The presence of these low-pollution tolerance organisms indicates appropriate water quality (Haney et al. 2013), and the HBI score of 3.9 places the reference site in the "Very Good" Hilsenhoff water quality category. Species evenness (E_H = 0.621) was decreased due to a high proportion of *Coleoptera psephenidae* "water pennies" collected (Table 10).

Table 10. Species of macroinvertebrates sampled at the reference site Fivemile Creek.

Order	Family	Common Name	Count	HBI Tolerance	Proportion
Coleoptera	Psephenidae	Water Pennies	115	4	0.507
Trichoptera	Odontoceridae	Strong Case-maker	27	0	0.119
Odonata	Coenagrionidae	Narrow-winged damselfly	26	9	0.115
Coleoptera	Elmidae	Riffle Beetle Larvae	9	4	0.040
Prosobranchia	Pleuroceridae	Gilled snail	7	4	0.031
Plecoptera	Perlidae	Common stonefly	7	1	0.031
Ephemeroptera	Ameletidae	Comb-mouthed Mayflies	6	1	0.026
Trichoptera	Helicopsychidae	Snail Casemaker	5	3	0.022
Ephemeroptera	Baetidae	Small Minnow Mayflies	5	4	0.022
Coleoptera	Ectopria	Water Penny Ectopria	4	4	0.018
Ephemeroptera	Heptageniidae	Flat-headed Mayfly	4	4	0.018
Coleoptera	Elmidae	Riffle Beetles (adult)	3	4	0.013
Tricladida	Dugesiidae	Flatworm	2	4	0.009
Oligochaeta	Tubificidae	Sludge worms	1	8	0.004
Isopoda	Asellidae	Isopod	1	8	0.004
Megaloptera	Corydalidae	Dobsonfly	1	5	0.004
Diptera	Limoniidae	Limoniid Crane Fly	1	6	0.004
Diptera	Athericidae	Aquatic Fly	1	2	0.004
Ephemeroptera	Dipseudopsidae	Pitot-Tube Caddisfly	1	4	0.004
Ephemeroptera	Ephemerellidae	Spiny Crawler Mayfly	1	4	0.004

The treatment site, Horse Creek East, had a much lower count of species (S = 7), with a correspondingly decreased Shannon-Wiener Diversity score (H = 1.63), zero EPT taxa found, and an HBI score of 5.3 (Table 11).

Table 11. Species of macroinvertebrates sampled at Horse Creek East.

Order	Family	Common Name	Count	HBI Tolerance	Proportion
Tricladida	Dugesiidae	Flatworm	7	4	0.4375
Pleuroceridae	Pulmonata	Lunged snail	3	7	0.1875
Diptera	Chironomidae	Midge	2	6	0.125
Odonata	Libellulidae	Skimmer	1	9	0.0625
Hemiptera	Veliidae	Riffle Bug	1	6	0.0625
Decapoda	Palaemonidae	Grass shrimp	1	5	0.0625
Coleoptera	Elmidae	Riffle Beetle Larvae	1	4	0.0625

Only two species of macroinvertebrates were found at the control site, Horse Creek North, which had very poor indices for species richness (S = 2) and Shannon-Wiener Diversity (H = 0.53; Table 12). The HBI tolerance score of 4.67, along with the treatment site score of 5.3, both fall within the "Good" Hilsenhoff water quality category.

Table 12. Species of macroinvertebrates sampled at the control site, Horse Creek North.

Order	Family	Common Name	Count	HBI Tolerance	Proportion
Tricladida	Dugesiidae	Flatworm	7	4	0.778
Pleuroceridae	Pulmonata	Lunged snail	2	7	0.222

Macroinvertebrate Shannon-Wiener diversity metrics were best predicted by "Developed, Low Intensity" land use, as well as "Velocity/Depth Regime" and "Riparian Vegetated Zone Width". Similar to fish diversity metrics, increased urban land development increases anthropogenic stress on stream systems, and decreases macroinvertebrate diversity (Bayes' factor = 0.390; Thornhill et al. 2017). In-stream habitat metric scores increased macroinvertebrate diversity for similar reasons to fish community assemblages, and the strong positive correlations with velocity/depth regime

(Bayes' factor = 0.256) and riparian vegetative zone width (Bayes' factor = 0.257) indicated moderate support for the importance of these aquatic and riparian habitat features in macroinvertebrate community diversity. Macroinvertebrate HBI scores indicated sensitivity to pollution, where species with lower HBI metrics were more sensitive to water quality impairment than those with high HBI resilience. As such, HBI was negatively correlated with velocity/depth regime (Bayes' factor = 0.380) and riparian vegetative zone width (Bayes' factor = 0.381) habitat metrics.

Although the results of Bayesian Inference methods highlight likely contributors to fish and macroinvertebrate community assemblage metrics, a number of shortcomings must be addressed. The results presented best represent a single snapshot in time due to lack of repeated sampling events. Future studies would be improved by conducting yearly evaluations of habitat and biotic assemblages, improving statistical power and increasing the number of methods available for statistical analysis. Although the correlation between biotic assemblage metrics and habitat parameters were often very strong, inference was weakened by the small number of samples (n=3) and Bayes' factors provide a range of interpretations, rather than a standard p-value.

3.3.3. Data Analysis

A full set of Bayes' factor and Pearson correlation coefficient data may be found in Appendix C. A summary table (Table 13) highlights significant findings (in terms of Bayes' factor evidence to support the alternative hypothesis) in the comparisons of biotic metrics and habitat assessment parameters. Bayes' Factor scores ranged from 0.17 to 2.679, with an average of 1.42. These data indicate that most habitat metrics assessed had marginal to no impact on fish and macroinvertebrate community metrics. Due to the small sample size, the Pearson correlation coefficients are misleading; values near -1 or 1 indicate a near-perfect linear relationship between measures of the dependent and independent variable. Such a relationship is extremely unlikely, especially in ecological research. The primary benefit of including Pearson correlation coefficients in this data is to evaluate the direction of the relationship between each factor; e.g., a positive relationship indicates that as an independent variable increases, the response of the dependent variable is expected to increase, and negative correlation coefficients predict a decrease in the dependent variable in response to an increase of the independent variable.

Table 13. Summary of Bayes' factor and Pearson correlation coefficient results.

Metric	Habitat or Land Use Parameter	Bayes' Factor	Pearson Correlation Coefficient
Fish Shannon Diversity	Developed, Low Intensity	0.23	-1.000
	Developed, Medium Intensity	0.311	-0.998
	Velocity/Depth Regime	0.255	0.999
	Riparian Vegetative Zone Width	0.254	0.999
Fish Species Richness	Pool Variability	0.286	0.998
Fish Species Evenness	Epifaunal Substrate/Available Cover	0.306	0.998
Macroinvertebrate Shannon Diversity	Developed, Low Intensity	0.390	-0.993
	Velocity/Depth Regime	0.256	0.999
	Riparian Vegetative Zone Width	0.257	0.999
Macroinvertebrate Species Evenness	Bank Vegetative Protection	0.171	1.000
Macroinvertebrate HBI	Velocity/Depth Regime	0.38	-0.994
	Riparian Vegetative Zone Width	0.381	-0.994

3.3.4. Vegetation Recovery and NDVI

NDVI analysis of the conservation easement treatment areas of the watershed revealed mixed results, largely due to the decrease in NDVI at the Horse Creek South site. This result may be explained by the exceptional drought year that occurred in 2022, increasing plant stress. According to rainfall accumulation history, Ottawa County had only received 74.22 centimeters of rainfall between January and August 2022. Meanwhile, the 2020 year had received 95.55

centimeters of rainfall between January and August (NOAA 2022). The small tributary at the Horse Creek South site quickly dried beginning in July 2022, which was among the driest seasons on record in the county. The main channel of Horse Creek retained a small amount of water, even through the driest months, leading to reduced stress at the Horse Creek East and Horse Creek North sites (Table 14).

Table 14. Summary of NDVI mean and standard deviation at three Horse Creek sites.

Site	NDVI Average (2020)	St. Dev (2020)	NDVI Average (2022)	St. Dev (2022)	% Change	Unpaired t-test (p-value)
Treatment	0.725	0.203	0.751	0.237	3.59	0.92
Control 1	0.578	0.138	0.595	0.224	2.94	0.94
Control 2	0.614	0.118	0.583	0.186	-5.05	0.86

Horse Creek East and Horse Creek North showed improvement in NDVI from 2020 to. NPP was estimated from NDVI for temperate forests using an empirical exponential relationship described in Sun et al. (2002; Equation 8), in units of (g C/m^2/month):

$$NPP = 218.2139(10^{0.2687 \cdot NDVI} - 1)$$

Equation 8. Calculation of NPP from NDVI in temperate forests.

At Horse Creek East in 2022, net primary productivity was estimated as 129 grams of carbon per square meter per month, or 1549 grams of carbon per square meter per year. At Horse Creek North, this estimate is 1165 grams of carbon per square meter per year. This range is similar to estimates of temperate deciduous forest (1200 g C m^{-2} yr^{-1}; Jackson and Jackson 1996) and indicates healthy growth of the riparian area of the watershed (Figure 11).

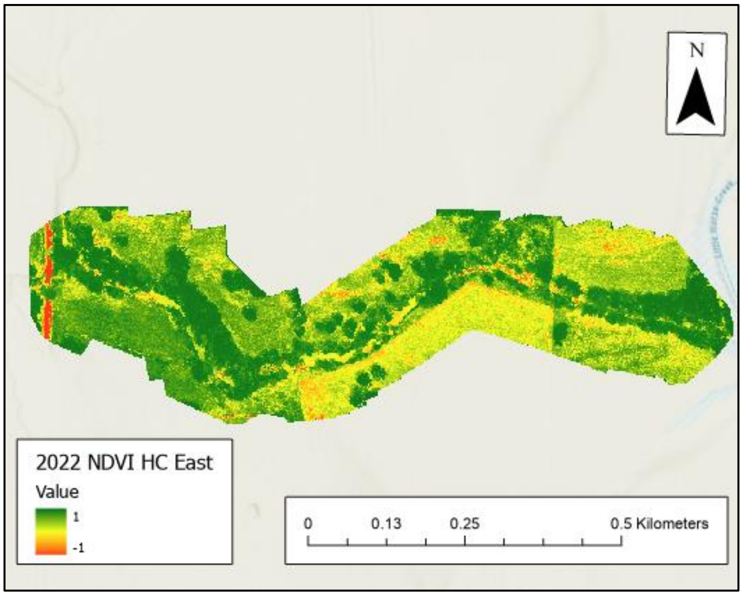


Figure 11. Example of the NDVI process applied to the treatment site. Imagery captured Summer 2022.

An unpaired t-test was used to determine whether the difference in NDVI was significant for the time series between 2020 and 2022 (Figure 12). The difference in NDVI was not significant for any of the three study sites at Horse Creek ($p > 0.05$). However, the trends in NDVI were positive for the sites that retained water throughout the dry summer months.

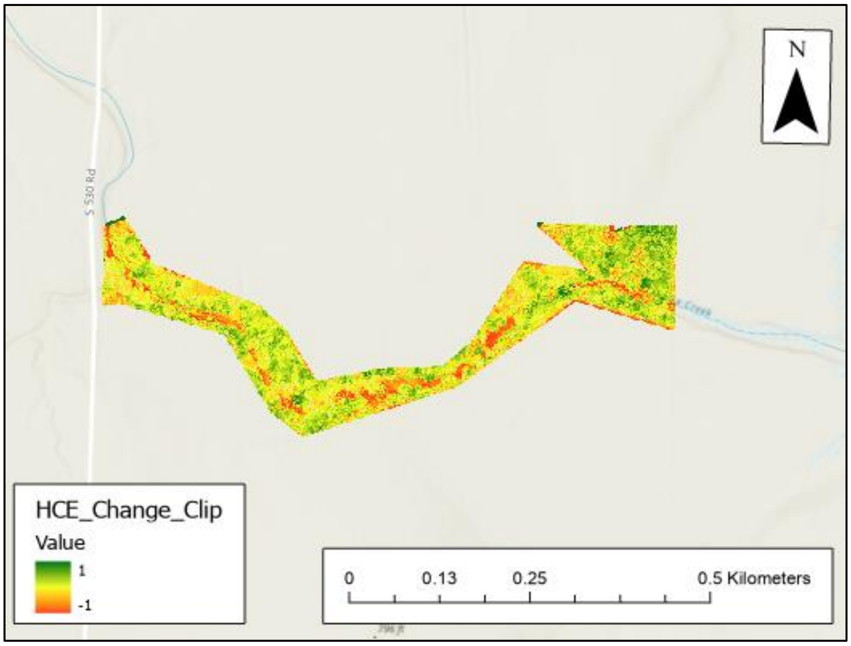


Figure 12. Example of raster math applied to subtract 2022 NDVI from 2020 NDVI within the conservation easement. Dark green areas indicate increases in NDVI.

Canopy volume (Table 15; Figure 13) increased at all three Horse Creek sites between 2020 and 2022. Canopy structure is correlated with aboveground biomass (Wen et al. 2017; Walter et al. 2018; Maimaitijiang 2019), indicating that vegetation biomass is increasing in the conservation easement areas.

Table 15. Canopy volume at three Horse Creek sites between 2020 and 2022.

Site	Canopy Volume (2020)	Canopy Volume (2022)	% Change
Horse Creek East	755,470 m^3	772,368 m^3	2.2
Horse Creek North	417,993 m^3	424,360 m^3	1.5
Horse Creek South	1,705,240 m^3	1,733,049 m^3	1.6

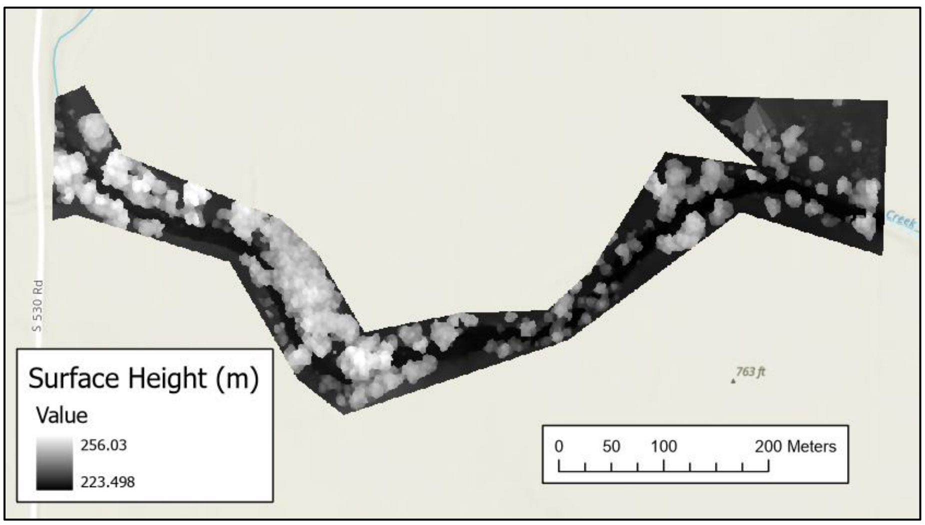


Figure 13. Digital surface model (DSM)-derived visualization of vegetation height at Horse Creek East within the conservation easement.

Further studies are needed to create a longer time series to assess whether these trends remain positive and become significant over a larger recovery period. Canopy volume is likely more accurately assessed using LIDAR point cloud data, and estimation of aboveground biomass is difficult without accompanying allometric models.

3.4. Conclusions

Biotic assemblages in the Horse Creek and Fivemile Creek watersheds responded to habitat and land use factors. Community metrics and indices showed that both fish and macroinvertebrate assemblages in the reference reach were greater than those in the treatment or control sites. Bayesian inference supports the hypothesis that land use and habitat metrics were drivers of differences in community dynamics between each site, and that the most influential metrics included riparian vegetative zone width, developed land use, and stream velocity/depth regime. These results supported the hypothesis that fish and macroinvertebrate community assemblage metrics were greatest at Fivemile Creek because of superior habitat assessment metrics and decreased anthropogenic land use in the watershed.

Riparian vegetation in the cattle exclusion conservation easements was showing evidence of recovery. Canopy volume increased approximately 2 percent at each site from 2020 to 2022, indicating that aboveground biomass was increasing due to lack of grazing pressure. NDVI increased at two of the three areas, indicating an increase in net primary productivity, but decreased in an area that became stressed by drought conditions in summer 2022. As a result, the hypothesis that study sites fenced in conservation easements will show increases in NDVI and canopy volume (as a proxy for aboveground biomass) due to decreased stress from livestock grazing was inconclusive.

References

Abel, P.D. Water Pollution Biology, First Ed; CRC Press: Boca Raton, **1996**, 296p. ISBN: 978-0748406197.

Antognelli, S. NDVI and NDMI vegetation indices: instructions for use. **2018**. https://www.agricolus.com/en/vegetation-indices-ndvi-ndmi/ (accessed Oct 22, 2022).

Barrella, W.; Petrere, M. Fish Community Alterations due to Pollution and Damming in Tiete and Paranapanema Rivers. *River Research and Applications* **2003**, 19, 59-76.

Bice, C.M.; Gehrig, S.L.; Zampatti, B.P.; Nicol, J.M.; Wilson, P. Flow-induced alterations to fish assemblages, habitat, and fish-habitat associations in a regulated lowland river. *Hydrobiologia* **2014**, 722(1), 205-22. DOI:10.1007/s10750-013-1701-8

Blattenberger, M.; Knepp, R.; Lingle, E.; Malar, A.; Mullins, N. Diversity of EPT taxa in relation to land use along Great Trough Creek. *Journal of Ecological Research* **2000**, 2, 47-52.

Cummings, C.L.; Alexander, H.M.; Snow, A.A.; Reiseberg, L.H.; Kim, M.J.; Culley, T.M. Fecundity selection in a sunflower crop-wild study: can ecological data predict crop allele changes? *Ecological Applications* **2002**, 12, 1661-71. DOI: 10.2307/3099930

Ellison, A. M. Bayesian Inference in Ecology. *Ecology Letters* **2004**, 7, 509-520. DOI: 10.1111/j.1461-0248.2004.00603.x

EPA. Indicators: Fish Assemblage. **2022**. https://www.epa.gov/national-aquatic-resource-surveys/indicators-fish-assemblage (accessed Nov 16, 2022)

Fleishman, E.; Nally, R.M.; Fay, J.P. Validation tests of predictive models of butterfly occurrence based on environmental variables. *Conservation Biology* **2003**, 17, 806-17. DOI: 10.1046/j.1523-1739.2003.02113.x

Gafny, S.; Goren, M.; Gasith, A. Habitat Condition and Fish Assemblage Structure in a Coastal Mediterranean Stream (Yarqon, Israel) Receiving Domestic Influent. *Hydrobiologia* **2000**, 422/423, 319-330. DOI: 10.1007/978-94-011-4164-2_26

Gonzalez, E.; Sher, A.A.; Tabacchi, E.; Masip, A.; Poulin, M. Restoration of Riparian Vegetation: A Global Review of Implementation and Evaluation Approaches in the International, Peer-Reviewed Literature. *J. Env. Manage* **2015**, 158, 85-94. DOI: 10.1016/j.envman.2015.04.033

Haney, J.F. et al. An Image-Based Key to Stream Insects. *University of New Hampshire Center for Freshwater Biology* **2013**. http://cfb.unh.edu/StreamKey/html/index.html

Hellawell, J.M. Biological Indicators of Environmental Pollution and Freshwater Management. Chapter in Pollution Monitoring Series: Springer Dordrecht, **1986**, 546p. ISBN: 978-94-010-8417-8

Heino, J.; Muotka, T.; Paavola, R. Determinants of macroinvertebrate diversity in headwater streams: regional and local influences. *Journal of Animal Ecology* **2003**, 72(3), 425-34. DOI: 10.1046/j.1365-2656.2003.00711.x

Hespanhol, L.; Vallio, C.S.; Costa, L.M.; Saragiotto, B.T. Understanding and interpreting confidence and credible intervals around effect estimates. *Brazilian Journal of Physical Therapy* **2019**, 23(4), 290-301. DOI: 10.1016/j.bjpt.2018.12.006

Huang, S.; Tang, L.; Hupy, J.P.; Wang, Y.; Shao, G. A Commentary Review on the use of Normalized Difference Vegetation Index (NDVI) in the era of Popular Remote Sensing. *Journal of Forestry Research* **2021**, 32, 1-6. DOI: 10.1007/s11676-020-01155-1

IBM. Bayesian Inference about Pearson Correlation. **2022**. https://www.ibm.com/docs/en/spss-statistics/saas?topic=statistics-bayesian-inference-about-pearson-correlation (accessed Oct. 12, 2022).

Jackson, A.R.W.; Jackson, J.M. Environmental Science: The Natural Environment and Human Impact. **2000**. Addison-Wesley Longman Publishing.

Jeffree, R.A.; Twining, J.R.; Thomson, J. Recovery of Fish Communities in the Finnis River, Northern Australia, Following Remediation of the Run Jungle Uranium/Copper Mine Site. *Environmental Science & Technology* **2001**, 35, 2932-2941.

King, A.J.; Tonkin, Z.; Mahoney, J. Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. *River Research and Applications* **2009**, 25, 1205-18. DOI: 10.1002/rra.1209

Lenat, D.R.; Smock, L.A.; Penrose, D.L. Use of Benthic Macroinvertebrates as Indicators of Environmental Quality. Chapter in Biological Monitoring for Environmental Effects **1980**.

Liu, H.; Dahlgren, R.A.; Larsen, R.E.; Devine, S.M.; Roche, L.M.; O'Geen, A.T.; Wong, A.J.Y.; Covello, S.; Jin, Y. Estimating Rangeland Forage Production using Remote Sensing Data from a Small Unmanned Aerial System (sUAS) and PlanetScope Satellite. *Remote Sensing* **2019**, 11. DOI: 10.3390/rs11050595

Maimaitijiang, M.; Sagan, V.; Sidike, P.; Maimaitiyiming, M.; Hartling, S.; Peterson, K.T.; Maw, M.J.W.; Shakoor, N.; Mockler, T.; Fritschi, F.B. Vegetation Index Weighted Canopy Volume Model for soybean biomass estimation from Unmanned Aerial System-based RGB imagery. *ISPRS Journal of Photogrammetry and Remote Sensing* **2019**, 151, 27-41. DOI: 10.1016/j.isprsjprs.2019.03.003.

Nagler, P.L.; Glenn, E.P.; Thompson, T.L.; Huete, A. Leaf Area Index and Normalized Difference Vegetation Index as Predictors of Canopy Characteristics and Light Interception by Riparian Species on the Lower Colorado River. *Agricultural and Forest Meteorology* **2004**, 125(1), 1-17. DOI:10.1016/j.agrformet.2004.03.008.

NOAA. Climate at a Glance: Ottawa County, Oklahoma. **2022**. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/county/rankings/OK-115/pcp/202208 (accessed Nov. 17, 2022).

Palmer, M.A.; Zedler, J.B.; Falk, D.A. Foundations of Restoration Ecology, 2nd ed. Island Press, **2016**. ISBN: 9781610916974

Penny, S.F. The Use of Macroinvertebrates in the Assessment of Point Source Pollution. In *Biological Monitoring of Freshwaters: Proceedings of a Seminar* **1985**, 205-15.

Pix4D. Pix4D Mapper Photogrammetry Software. https://www.pix4d.com/product/pix4dmapper-photogrammetry-software (accessed Aug 13, 2022).

Platt, W.J.; Beckage, B.; Doren, R.F.; Slater, H.H. Interactions of large-scale disturbances: prior fire regimes and hurricane mortality of savannah pines. *Ecology* **2002**, 83, 1566-72. DOI: 10.2307/3071975

Rosenberg, D.M.; Resh, V.H. Freshwater Biomonitoring and Benthic Macroinvertebrates. Springer, New York, **1993**. 488p. ISBN: 978-0-412-02251-7

Santora, J.A.; Schroeder, I.D.; Bograd, S.J.; Chavez, F.P.; Cimino, M.A.; Fiechter, J.; Hazen, E.L.; Kavanaugh, M.T.; Messie, M.; Miller, R.R.; Sakuma, K.M.; Sydeman, W.J.; Wells, B.K.; Field, J.C. Pelagic biodiversity, ecosystem function, and services: an integrated observing and modeling approach. *Oceanography* **2021**, 34(2), 16-37. DOI: 10.5670/oceanog.2021.212

Shaw, H. Y. Online conservation guide for *Etheostoma camurum*. *New York Natural Heritage Program* **2022**. https://guides.nynhp.org/bluebreast-darter/ (accessed Nov 11, 2022).

Soldner, M.; Stephen, I.; Ramos, L.; Angus, R.; Wells, N.C.; Grosso, A.; Crane, M. Relationship between macroinvertebrate fauna and environmental variables in small streams of the Dominican Republic. *Water Research* **2004**, 38(4), 863-74. DOI: 10.1016/S0043-1354(03)00406-8

Statology. Shannon Diversity Index: Definition & Example. **2021**. https://www.statology.org/shannon-diversity-index/ (accessed Oct. 12, 2022)

Sun, R.; Chang-ming, L.; Qi-jiangl, Z. Dynamic change of net primary productivity and fractional vegetation cover in the Yellow River Basin using multi-temporal AVHRR NDVI data. *Journal of Geographical Sciences* **2002**, 12(1), 29-34. DOI: 10.1007/BF02837424

Thornhill, I.; Batty, L.; Death, R.G.; Friberg, N.R.; Ledger, M.E. Local and landscape scale determinants of macroinvertebrate assemblages and their conservation value in ponds across an urban land-use gradient. *Biodiversity and Conservation* **2018**, 26, 1065-86. DOI: 10.1007/s10531-016-1286-4

Valone, T.J.; Brown, J.S. Measuring patch assessment abilities of desert granivores. *Ecology* **1989**, 70, 1800-10. DOI: 10.2307/1938113

Vorsino, A.E.; Fortini, L.B.; Amidon, F.A.; Miller, S.E.; Jacobi, J.D.; Price, J.P.; Gon, S.O.; Koob, G.A. Modeling Hawaiian ecosystem degradation due to invasive plants under current and future climates. *PLoS ONE* **2014**, 9(5). DOI: 10.1371/journal.pone.0095427

Wade, P.R. Bayesian Methods in Conservation Biology. *Conservation Biology* **2000**, 14(5), 1308-1316.

Walter, J.; Edwards, J.; McDonald, G.; Kuchel, H. Photogrammetry for the estimation of wheat biomass and harvest index. *Field Crops Research* **2018**, 216, 165-74. DOI: 10.1016/j.fcr.2017.11.024

Weaver, M.J.; Magnuson, J.J.; Clayton, M.K. Distribution of littoral fishes in structurally complex macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences* **1997**, 54, 2277-89. DOI: 10.1139/f97-130

Wen, Z.; Ma, M.; Zhang, C.; Yi, X.; Chen, J.; Wu, S. Estimating seasonal aboveground biomass of a riparian pioneer plant community: An exploratory analysis by canopy structural data. *Ecological Indicators* **2017**, 83, 441-50. DOI: 10.1016/j.ecolind.2017.07.048.

Winemiller, K.O.; Tarim, S.; Shormann, D.; Cotner, J.B. Fish assemblage structure in relation to environmental variation among Brazos River oxbow lakes. *Transactions of the American Fisheries Society* **2000**, 129, 451-468.

Chapter 4 - Ecosystem Metabolism and Function in the Horse Creek Watershed of the Grand Lake o' the Cherokees, Oklahoma

Abstract: Riparian ecosystems are transitional between aquatic and terrestrial environments, providing a wide range of ecological functions such as nutrient cycling, biological productivity, and organic matter decomposition. Although traditional assessments of riparian ecosystem restoration quantify structural components, including biotic assemblages and habitat structure, few evaluate the restoration of function. The focus of this study was to evaluate the impact of conservation easements in Horse Creek on functional ecosystem indicators. Net primary productivity (NPP) was evaluated using the open diel oxygen method. No significant relationships were found between NPP and water physiochemistry, habitat, or land use parameters. A companion study was conducted on rates of decomposition in Horse Creek and Fivemile Creek, a regional reference stream. A cotton tensile strength assay was chosen to measure the relative capacity of streams to process organic matter. Cotton strips were deployed monthly at three Horse Creek sites and one Fivemile Creek site, and assessed for losses of tensile strength due to incubation. These loss rates were compared to sub-watershed land use, habitat assessment, and water quality parameters to evaluate drivers behind changes in decomposition at each site. Results indicated that rates of decomposition were lowest at the reference site, were greater at the treatment (conservation easement) site and were greatest at the two control (non-easement) sites in the watershed. Agricultural land use (as hay and pasture) was strongly correlated with increases in decomposition rate, as well as levels of reactive phosphorus and riparian vegetative zone width. These results illustrated the importance of functional assessments as tools to evaluate conservation easement success.

Keywords: Conservation easement, water quality, habitat assessment, decomposition, riparian ecosystem, aquatic ecosystem

4.1. Introduction

Traditional stream assessments rely on structural indicators because the methods are usually inexpensive, easy to replicate, and comparable between sites. Indicators of ecosystem functions, such as primary production, respiration, and organic matter decomposition, have been neglected (Young et al., 2008) because of the challenges in proper assessment. Many ecosystem processes are not directly linked to structure (Doehring et al., 2019). Since many projects attempt to maximize linear or areal restoration per dollar, there is rarely a distinction between “high quality” and “low quality” habitat, or whether or not the habitat produced was critically needed for important species (Rubin et al., 2017). Monitoring target populations may also not prove to be effective as an evaluation metric; for example, long-term implementation of in-stream structures for salmonid habitat have not produced documented evidence of population increases (Stewart et al., 2009).

Functional indicators of stream ecosystem processes can be described by differences in metabolism and rates of organic matter decomposition (Doehring et al., 2019) between healthy and impaired stream ecosystems. These metrics are not commonly evaluated in traditional stream monitoring and assessment, due to a lack of functional indicators that directly measure the rate of ecological processes (Lecerf et al. 2006), but can be used to describe stream ecosystem health (Pingram et al., 2019). The net primary production (NPP) of an aquatic ecosystem can be computed from an open diel oxygen curve and is defined as the gross primary production (GPP) minus respiration (R) (Demars et al., 2015).

GPP is primarily controlled by light, temperature, and nutrients, and respiration is mainly driven by the supply of degradable organic matter and temperature (Ferreira et al. 2020). Stream metabolism is sensitive to environmental pressures, such as pollution (Aristi et al. 2015), eutrophication (Gucker and Pusch 2006), and channelization (Hope et al. 2014). Potential increases to ecosystem respiration include higher water temperatures caused by riparian deforestation and inputs of organic material with high oxygen demand (Arroita et al. 2019). It is hypothesized that non-conservation easement sites (controls) will have higher NPP than the conservation site (treatment) or the reference site, due to increased algal and macrophytic productivity in the higher nutrient concentration, warmer temperature reaches of the stream.

Decomposition rates show complex responses to environmental change (Ferreira et al. 2020). The activity of bacteria and fungi is a major contributor to the breakdown of cellulose molecules, the primary carbohydrate of leaf litter (Chen et al. 2020). This activity, in turn, is influenced by nutrient concentrations (Woodward et al. 2012), water temperatures (Webb et al. 2019), macroinvertebrate communities (Ferreira and Canhoto 2014), and the spatial heterogeneity of habitat variables such as substrate size and water depth (Bastias et al. 2020). The hypothesis for this portion of the study is that decomposition rates will be lower at the reference site than at the treatment site, due to improved water quality and response to less anthropogenically-disturbed watershed land and habitat characteristics. At Horse Creek, it is hypothesized that the Horse Creek East easement site (treatment) will exhibit lower rates of decomposition than non-easement sites (controls), due to improved habitat metrics and reduction of anthropogenic stress on the aquatic ecosystem.

One method gaining attention for measuring organic matter decomposition in streams is the cotton tensile strength loss (CTSL) test. This method improves upon the traditional leaf litter mass loss assay by standardizing the material used (untreated cotton strips). The CTSL assay also decomposes more quickly than leaf litter, keeping incubation times in the field short. The method works by attaching cotton strips to a nylon rope, anchored into the stream substrate. As bacteria, fungi, and macroinvertebrates break down the cotton strips, tensile strength is lost. Tensile strength can be quantified in the laboratory. This tensile loss rate can be compared to other reaches or across time (Tiegs et al., 2007).

4.2. Materials and Methods

4.2.1. Open Diel Oxygen / Productivity

Measurements of pH, dissolved oxygen, and temperature were taken at each site using field-deployable water quality sondes (YSI Model 6920 v2) concurrent with the deployment of cotton strips. These measurements were taken at 15-minute intervals for a minimum period of 36 hours to generate a diel curve. Methods for calculating open diel oxygen were adapted from Demars (2015), based on computations by Odum (1956).

Net primary productivity (Equation 9) is a function of:

$$q = p - r \pm d + a$$

Equation 9. Calculation of the dissolved oxygen rate of change.

where "q" is the dissolved oxygen rate of change (in units of g O_2 m^{-3} hr^{-1}), "p" is the photosynthetic rate, "r" is the respiration rate, "d" is the rate of oxygen diffusion across the air-water interface, and "a" is the rate of oxygen accrual from groundwater or surface water. For all calculations, "a" was considered negligible. The rate of oxygen diffusion across the air-water interface "d" is a product of the diffusion constant "k" times the saturation deficit "SD". The value for the diffusion constant “k” was assumed to be 0.05, and the saturation deficit was calculated the difference between 100% dissolved oxygen saturation and the observed saturation. Productivity was assessed in 3-hour time steps over the diel curve to generate values of GPP, R, and NPP for each site for each month in units of g O_2 m^{-2} yr^{-1} (Figure 14).

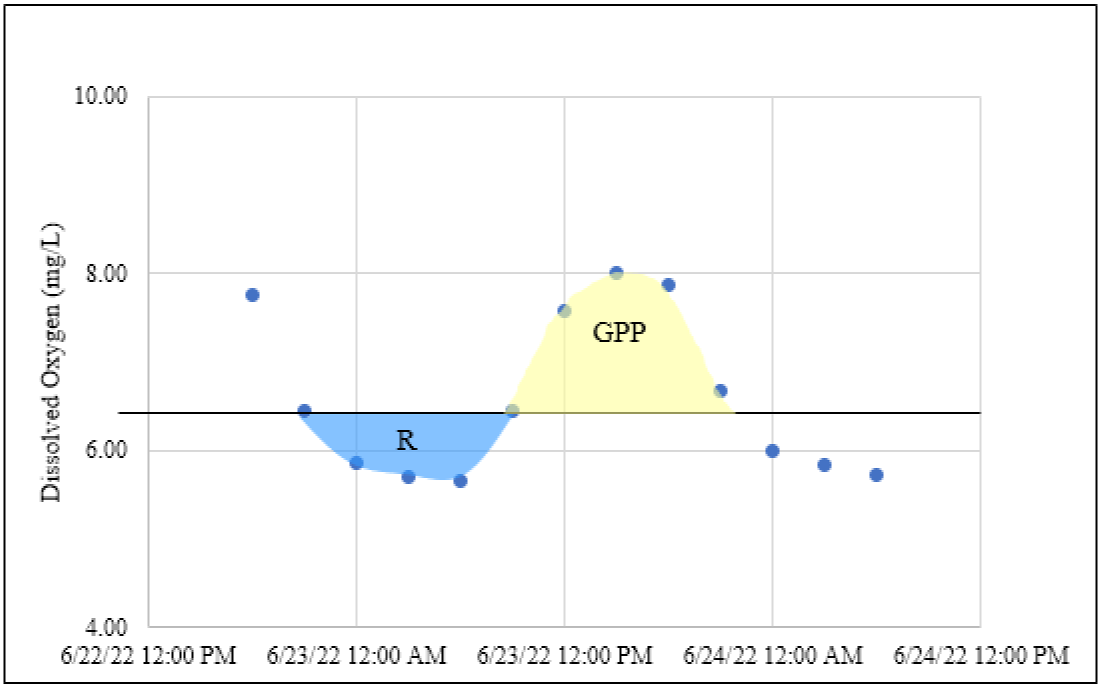


Figure 14. Estimation of GPP and R from diel oxygen curve.

4.2.2. Cotton Tensile Strength Loss

The methods used in this study were adapted from Tiegs et al. (2013). Long strips of cotton canvas approximately 6-cm wide were roughly cut from a bolt of cotton canvas. These long strips were cut into shorter (approximately 1.5-m long) strips for easier management. Individual threads were pulled from the long edge of each strip until a single thread delineated the “edge” of the fabric. Individual long threads were removed from the edge each strip until the strip was 28 threads wide. The fray was trimmed to approximately 3-mm in width from the edge of the long strip. Once the long strip was created, the strip was cut into 8-cm segments. Each short strip was rolled and passed between the index finger and thumb to increase the “fuzziness” of the frayed edges. This process was repeated until enough cotton strips had been produced for the month’s deployment.

The batch of created strips was thoroughly mixed together and dried in an oven at 40°C for 48 hours to drive off any excess moisture. Once dried the cotton strips were individually weighed on an analytical balance to the nearest 0.0001 g and randomly assigned to one of five batches – a laboratory control, the two control sites, the reference site, and the treatment site. Ten strips were weighed, assigned to each set, and given an identification number, for a total of 50 strips per sampling event.

For the treatment strips, a small hole was created in each cotton strip approximately 2 cm from the short edge. A thumbtack was used to place the hole in between two cotton threads to avoid tearing the material. Using this pilot hole, a small nail was pushed through the hole to create an opening for the attachment. A thin, flexible threaded key ring was pushed through the hole, then beads were added to the ring to provide the strip’s identification number. Each strip was then attached to a 1-meter-long section of nylon rope with loops tied into the body of the rope (Figure 15). Five cotton strips were attached to each rope, with two ropes consisting of the 10 strips for each site.

Figure 15. A cotton strip prepared for deployment at Horse Creek.

Cotton strips were deployed at four sites – three in the Horse Creek watershed, and one at the reference site on Fivemile Creek. Treatment site strips were deployed in the stream at a downstream portion of the cattle exclusion conservation easement (36º40’45.12”N, 94º55’21.24”W). Control site 1 strips were deployed upstream of the conservation easement (36º41’19.49”N, 94º56’22.96”W). Control site 2 strips were deployed outside of the conservation on the Little Horse Creek tributary (36º41’8.89”N, 94º54’48.21”W). The reference strips were deployed at Fivemile Creek upstream of the S680 Road Bridge (36º59’17.61”N, 94º38’43.49”W).

After the strips had been incubated in the field for 14 days, they were retrieved from the stream and cleaned by rinsing off any organic material and gently rubbing away any dirt or attached algae with a soft bristle brush. Each strip was submerged in a solution of 80% ethanol for 30 seconds to kill bacteria and macroinvertebrates before being packaged and returned to the laboratory. At the laboratory, the control strips were similarly submerged in 80% ethanol to control for any impacts of chemical leaching, and all strips were placed back into their identification tins and dried in a

40ºC oven for a period of approximately two days or until completely dry. Identification tags were removed and each strip was weighed to assess the mass loss of each strip. Cotton strips were stored in a desiccator at all times when not being weighed or prepared for tensile strength.

Strips were prepared for cotton tensile strength loss assessment by placing an approximately 2-cm-wide piece of duct tape on the ends of each strip. This procedure was found to improve results by providing a better grip in the jaws of the tensile tester in a trial run and did not affect the failure point of the cotton strips in tensile testing. A tensometer (United Model SSTM-10KN; SN# 0113504) was programmed to pull apart samples at a consistent 2 cm/minute. Individual strips were pulled by the tensometer at a constant rate until the strip reached failure, set as a 60% loss of peak tensile strength. The peak force applied to the cotton strips before failure was recorded as "tensile strength". This process was repeated for all control and test strips.

4.2.3. Water Quality

In addition to physical water quality parameters using water quality sondes, anion concentration data were generated in conjunction with the deployment of cotton strips. At each site, 250-mL samples of stream water were collected. Head space was eliminated in each sample by gently squeezing air out of each sample bottle and capping. Samples were kept on ice and returned to the laboratory. Anions were quantified using a SEAL AQ300 discrete analyzer. Standards and samples were prepared following manufacturer standard operating procedures. Anions evaluated included nitrate, nitrite, soluble reactive phosphorus, chloride, and sulfate. Concentrations of anions at each site for each month were used in stepwise regressions to evaluate the impact of nutrient concentrations on ecosystem functional attributes.

4.2.4. Stepwise Regression

Stepwise regression was utilized in the analysis of these data. Stepwise regression fits a regression model to a list of predictor variables (Draper and Smith 1981). Usually, this takes the form of adding or removing independent variables from a model and testing for fit using F-tests or T-tests. This process is repeated on all predictor variables until the addition or removal of variables negatively impacts the model fit (Hocking 1976). Stepwise regressions in this context provided some benefits to the analysis of productivity and CTSL in this research. The large number of predictor variables (e.g., water quality parameters, land use classes, habitat assessment categories) were efficiently parsed by the use of stepwise linear regressions, fine-tuning the model to the "best" predictor variables (Wang and Jain 2003). Given the numerous articles on downsides and pitfalls with stepwise regression (Thompson 1995; Smith 2018; Lewis-Beck 1978), a conservative approach was used to hypothesize mechanisms at play at each of the sample sites.

SPSS Software (version 28.0.0) was used in the analysis of stepwise regressions. Samples were listed by site and by month. Mean values of NPP and CTSL rate were added as the variables "NPP" and "CTSLRate" for each site and each month. Values for water quality parameters (anions as nitrate, nitrite, soluble reactive phosphorus, chloride, and sulfate; mean pH; mean water temperature; habitat assessment scores; sub-watershed land use and land coverage as percentage of the watershed) were added as individual variable classes, resulting in two categorical variables (Site and Month) and 39 continuous variables. The linear regression tool was utilized to complete the stepwise analysis. Stepping method criteria were set to use a probability of F to enter variables at $F \geq 0.05$ and remove them at $F \leq 0.10$. Collinearity diagnostics were used to exclude independent variables that were highly correlated with one another.

Outputs from the linear regression included which variables (predictors) were kept in analysis; the model's R and R^2 values; an ANOVA summarizing the sum of squares, degrees of freedom, mean square, F value, and significance; standardized beta coefficients and significance of each predictor; collinearity diagnostics; and residuals statistics. Sets of predictors were run as batches to improve model output and analyze the impact of each category of impact (water quality parameters, habitat assessment parameters, and sub-watershed characteristics).

4.2.5. Kruskal-Wallis Test

In order to determine if there was a significant difference between sites for NPP or CTSL rate, a Kruskal-Wallis test was run. The test extends the Mann-Whitney U test to more than two groups, and determines whether the population medians were equal (Lomuscio 2021). The Kruskal-Wallis test is nonparametric. The hypotheses for the Kruskal-Wallis test were the null hypothesis, where the population medians are equal, and the alternative hypothesis, where population medians are not equal. The test statistic, H, is calculated as:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1)$$

Equation 10. Calculation of the Kruskal-Wallis test statistic.

where N is the total sample size, k is the number of groups, R_i is the sum of ranks for group i, and n_i is the sample size of group i. H is compared to the critical chi-square value with k-1 degrees of freedom. If the critical chi-square value is less than the H statistic, the null hypothesis is rejected. If H is greater than the critical chi-square value, then the null hypothesis is accepted.

4.3. Results and Discussion

4.3.1. Open Diel Oxygen / Productivity

The open diel oxygen curves generated by monthly sampling showed predictable increases in dissolved oxygen due to photosynthesis during daylight hours and decreases in oxygen due to respiration during nighttime (Figure 16).

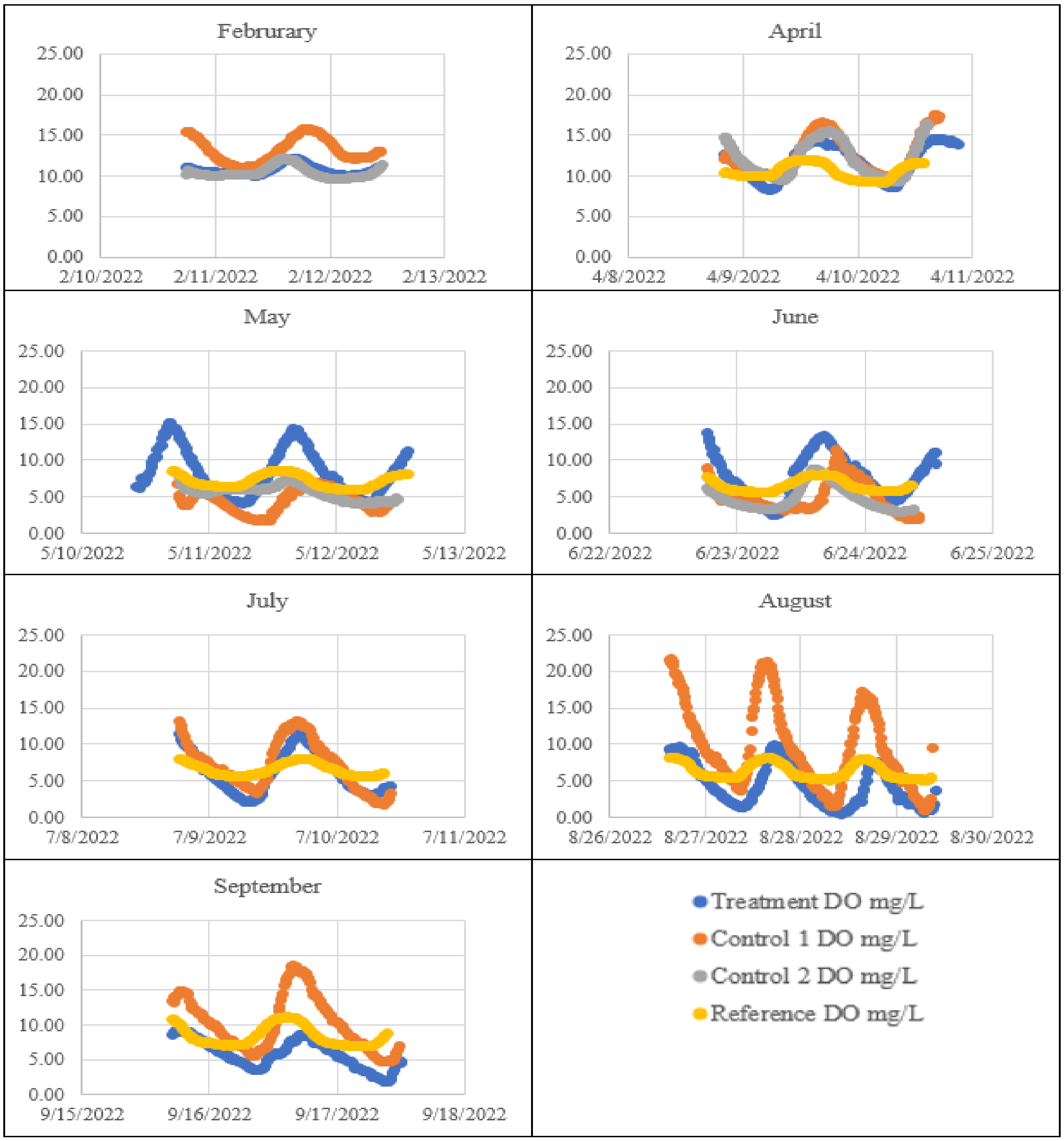


Figure 16. Diurnal dissolved oxygen curves for each site at each month.

Net primary productivity values were variable throughout the study period. The highest values for NPP occurred when algae blooms or increases in the growth of macrophytes occurred, likely increasing the amount of dissolved oxygen in the water via photosynthesis. The treatment site had the highest values of NPP from the months of April through July, and an algae bloom in June produced the highest NPP of any site throughout the study period. A macrophyte bloom in August increased NPP in Control site 1, and NPP remained high in September. The reference site had generally low values of NPP throughout the study period (Table 16). Algae and macrophytes at the reference site did not grow as vigorously at any point of the year as the treatment or control sites at Horse Creek.

Table 16. Summary table of NPP values (in g/m2/yr) from each site during the study period.

NPP ($g/m^2/yr$)	Treatment	Control 1	Control 2	Reference
February	351	546	188	x
April	1078	1052	570	-51
May	1426	621	-159	131
June	2440	803	601	387
July	598	342	x	324
August	1033	2094	x	275
September	-35	444	x	346

x = Data not collected.

An independent samples Kruskal-Wallis test was conducted to determine if means of NPP were different between sites. The null hypothesis was that the distribution of NPP was the same across all sites, and the alternative hypothesis was that the distribution of NPP was different. The null hypothesis was rejected in favor of the alternative hypothesis; the p-value of 0.03 was less than the confidence interval of $\alpha=0.05$, indicating a significant difference between the four sites (Figure 17).

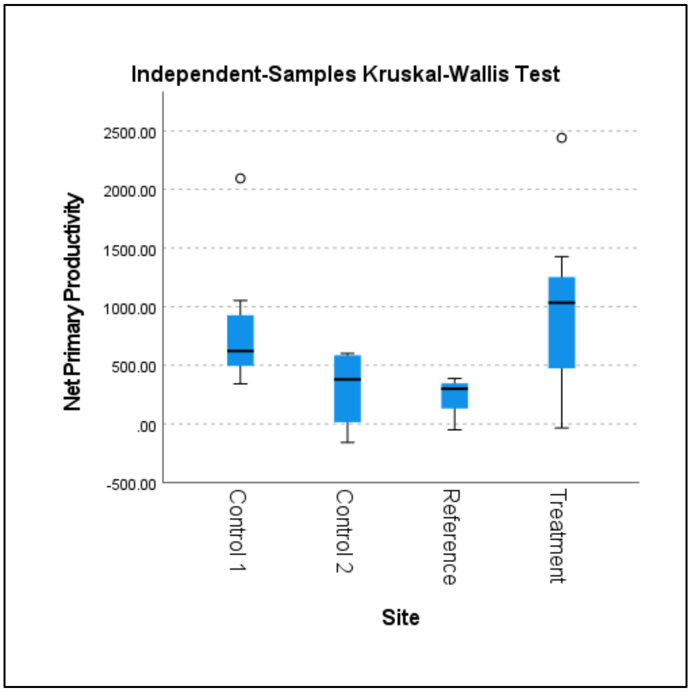


Figure 17. Results of the Kruskal-Wallis test on NPP between the four sites.

The site with the highest median NPP was the treatment site, followed by Control site 1, Control site 2, then the reference site. Comparison of NPP with water physiochemistry, habitat metrics, and land use parameters with stepwise regressions yielded no statistically significant relationships. However, there was a significant and positive relationship between NPP and CTSL rate ($p = 0.03$). Other than decomposition, none of the metrics studied had sufficient explanatory power to describe changes in NPP. In addition to temperature and nutrient concentrations, productivity is driven by light exposure (Ferreira et al. 2020). Light exposure was not assessed at any of the sites, and future studies could incorporate it to help explain differences in NPP.

The hypothesis that NPP would be highest in the non-conservation control sites was not supported; the highest NPP was in the riparian conservation easement treatment area. Increases in NPP were associated with algal and macrophytic production, but conditions at each site were variable throughout the study period. The reference site did not have the same algal or macrophytic production than the treatment site or Control site 1; therefore, NPP remained low. Warm, stagnant conditions at the treatment site led to an algae bloom in June, which increased NPP, but when the algae died off, its decomposition led to an increase in respiration and net negative NPP values by September.

4.3.2. Cotton Tensile Strength Loss

Values of CTSL rate indicated differences between each site. Generally, strips deployed at the reference site exhibited the lowest rates of decomposition in terms of CTSL/day, followed by the treatment site, then the two control sites (Table 17).

Table 17. Mean cotton tensile strength loss rate (%/day).

	Treatment	Control 1	Control 2	Reference
February	0.9	1.7	3.7	0.8
April	x	x	6.7	2.0
May	6.8	6.9	6.9	4.8
June	7.5	8.1	7.6	4.7
July	5.9	6.7		3.3
August	5.7	6.9		2.9
September	4.9	6.2		2.5

x = Samples lost due to flooding.

Unfortunately, exceptional drought conditions throughout the summer months made it impossible to generate accurate data in the Little Horse Creek system, since the small tributary completely dried up (Figure 18). Cotton strips were still deployed, but cotton tensile strength values generated from these deployments were not used in statistical analysis.

Figure 18. Little Horse Creek during drought conditions, summer 2022.

Mean values for CTSL rate largely highlight the difference between the reference stream, the treatment site, and the two control sites. For each month, cotton strips at the reference had a lower decomposition rate than any Horse Creek sites, indicating that Horse Creek suffers stresses imposed upon it by human activities (Gessner and Chauvet 2002). Several studies have indicated that leaf litter decomposition can be affected by nutrient concentration (Rosemond et al. 2002; Grattan and Suberkropp 2001), especially nitrogen and phosphorus. Nitrate ($p = 0.12$) and phosphorus ($p = 0.09$) were among the two best predictors for changes in cotton tensile strength loss rates in terms of anion concentrations (Table 18).

Table 18. Stepwise regression summary of water quality parameters as predictors for CTSL rate.

Water Quality Parameter	Coefficient	Significance
Nitrate (NO3+NO2)	-0.30	0.12
Soluble Reactive Phosphorus	0.55	0.09
Mean Temperature	0.68	< 0.01
Net Primary Production	0.46	0.03
Hay/Pasture Land Use	0.42	0.04
Riparian Vegetative Zone Width	-0.63	0.07

The best predictor for cotton tensile strength loss rates at these sites was the mean temperature of the water during deployment ($p < 0.01$). The positive coefficient showed that as water temperature increased, decomposition rates also increased. Net primary production was also strongly correlated with decomposition as CTSL rates ($p = 0.03$). The percentage of hay/pasture land use in the watershed was a strong predictor of decomposition in the streams ($p = 0.04$) The positive beta coefficient suggests that as hay/pasture land use increased, CTSL rate also increased. These findings support cattle grazing in the watershed had a negative impact on decomposition rates in the streams. Further corroboration comes from the relatively high correlation between riparian vegetative zone width and cotton tensile strength loss rates ($p = 0.07$). An inverse relationship existed, as evidenced by the negative beta coefficient – as riparian vegetative zone width increased, cotton tensile strength loss decreased.

An overall comparison of each site through all seven sampling events was also conducted, following the Kruskal-Wallis independent samples method. The null hypothesis of the distribution of CTSL rate being the same across all sites was rejected with a p-value of 0.03 (Figure 19).

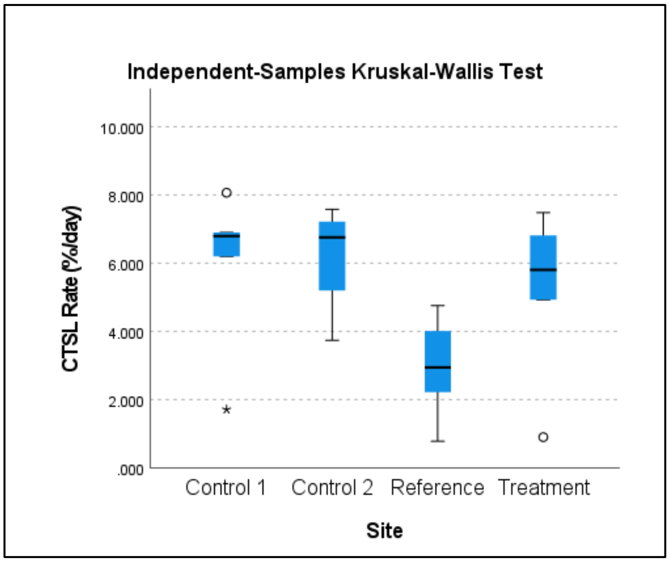


Figure 19. Independent Samples Kruskal-Wallis Test for CTSL Rate at each site across the entire testing period.

4.4. Conclusions

Although stream and riparian restoration projects emphasize both structural and functional improvement, stream bioassessment rarely considers ecosystem function. Although biotic assemblages, water quality parameters, and water chemistry are relatively easy and inexpensive to quantify, they do not always provide a holistic picture of ecosystem integrity. Organic matter decomposition and ecosystem metabolism are useful indicators for stream and riparian assessment. Rates of aquatic ecosystem productivity did not respond as predicted in the hypothesis. Horse Creek North, the non-conservation control site, did not exhibit the highest NPP. Fivemile Creek, the reference site, lacks macrophytes and has very low amounts of algae, likely due to decreased nutrient concentrations. The treatment site at Horse Creek East exhibited the highest median rate of NPP throughout the study period. Therefore, the hypothesis that non-conservation sites at Horse Creek would produce the highest rates of NPP was not supported. This study could be improved by examining ecosystem productivity at longer scales (integrating long-term regular sampling of dissolved oxygen), integrating light exposure at each site, or studying macrophytes and periphyton that may contribute dissolved oxygen during photosynthesis to the water column.

The reference system exhibited the lowest rate of decomposition, and statistical analysis revealed correlations with improved watershed land use metrics, water quality and temperature, and in-stream and riparian habitat. Future studies would benefit from expanding the scope of the cotton tensile strength assay; including responses to stream flow regime (riffle/pool/run), microbial analysis of the water column and of cotton strip colonizers, and macroinvertebrate-specific decomposition rates (by utilizing macroinvertebrate-excluding mesh bags) would improve the understanding of the response of cotton strips to ecosystem structure and community metrics.

References

Aristi, I.; von Schiller, D.; Arroita, M.; Barcelo, D.; Ponsati, L.; Garcia-Galan, M.J.; Sabater, S.; Elosegi, A.; Acuna, V. Mixed effects of effluents from a wastewater treatment plant on river ecosystem metabolism: subsidy or stress? *Freshwater Biology* **2015**, 60(7), 1398-1410. DOI: 10.1111/fwb.12576.

Bastias, E.; Bolivar, M.; Ribot, M.; Peipoch, M.; Thomas, S.A.; Sabater, F.; Marti, E. Spatial heterogeneity in water velocity drives leaf litter dynamics in streams. *Freshwater Biology* **2020**, 65, 435-45. DOI: 10.1111/fwb.13436

Chen, Z.; Chen, X.; Wang, C.; Li, C. Foliar cellulose and lignin degradation of two dominant tree species in a riparian zone of the Three Gorges Dam Reservoir, China. *Frontiers in Plant Science* **2020**, 11. DOI: 10.3389/fpls.2020.569871.

Draper, N.R.; Smith, H. Applied Regression Analysis, Second Edition. **1981**. John Wiley & Sons, New York.

Ferreira, V.; Canhoto, C. Effect of experimental and seasonal warming on litter decomposition in a temperate stream. *Aquatic Science* **2014**, 76, 155-63. DOI: 10.1007/s00027-013-0322-7

Ferreira, V.; Elosegi, A.; Tiegs, S.D.; von Schiller, D.; Young, R. Organic matter decomposition and ecosystem metabolism as tools to assess the functional integrity of streams and rivers – a systematic review. *Water* **2020**, 12(12), 3523. DOI: doi.org/10.3390/w12123523

Gessner, M.O.; Chauvet, E. A Case for using Litter Breakdown to Assess Functional Stream Integrity. *Ecological Applications* **2002**, 12(2), 498-510. DOI: 10.2307/3060958

Grattan, R.M.; Suberkropp, K. Effects of Nutrient Enrichment on Yellow Poplar Leaf Decomposition and Fungal Activity in Streams. *Journal of the North American Benthological Society* **2001**, 20, 33-43.

Gucker, B.; Pusch, M.T. Regulation of nutrient uptake in eutrophic lowland streams. *Limnology and Oceanography* **2006**, 51(3), 1443-53. DOI: 10.4319/lo.2006.51.3.1443

Hope, A.J.; McDowell, W.H.; Wollheim, W.M. Ecosystem metabolism and nutrient uptake in an urban, piped headwater stream. *Biogeochemistry* **2013**, 121, 167-87. DOI: 10.1007/s10533-013-9900-y

Lewis-Beck, M.S. Stepwise Regression: A Caution. *Political Methodology* **1978**, 5(2), 213-40. https://www.jstor.org/stable/25791533

Lomuscio, S. Getting started with the Kruskal-Wallis Test. From the University of Virginia Library Research Data Services. https://data.library.virginia.edu/getting-started-with-the-kruskal-wallis-test/ (accessed Dec. 3, 2022)

Hocking, R.R. The Analysis and Selection of Variables in Linear Regression. *Biometrics* **1976**, 32.

Holtgrieve, G.W.; Schindler, D.E.; Branch, T.A.; A'mar, Z.T. Simultaneous quantification of aquatic ecosystem metabolism and reaeration using a Bayesian statistical model of oxygen dynamics. *Limnol. Oceanogr.* **2010**, 55(3), 1047-63. DOI: 10.4319/lo.2010.55.3.10471047.

Roberts, B.J.; Mulholland, P.J.; Hill, W.R. Multiple scales of temporal variability in ecosystem metabolism rates: results from 2 years of continuous monitoring in a forested headwater stream. *Ecosystems* **2007**, 10, 588-606. DOI: 10.1007/s10021-007-9059-2

Rosemond, A.D.; Pringle, C.M.; Ramirez, A.; Paul, M.J.; Meyer, J.L. Landscape Variation in Phosphorus Concentration and Effects on Detritus-Based Tropical Streams. *Limnology and Oceanography* **2002**, 47, 278-89. DOI: 10.4319/lo.2002.47.1.0278

Smith, G. Step Away from Stepwise. *Journal of Big Data* **2018**, 5(32). DOI: 10.1186/s40537-018-0143-6.

Thompson, B. Stepwise Regression and Stepwise Discriminant Analysis Need Not Apply Here: A Guidelines Editorial. *Educational and Psychological Measurement* **1995**, 55(4). DOI: 10.1177/0013164495055004001

Wang, G.; Jain, W. Regression Analysis Modeling & Forecasting. **2003**. Graceway Publishing Company.

Webb, J.R.; Pearce, N.J.T.; Painter, K.J.; Yates, A.G. Hierarchical variation in cellulose decomposition in least-disturbed reference streams: a multi-season study using the cotton strip assay. *Landscape Ecology* **2019**, 34, 2353-69. DOI: 10.1007/s10980-019-00893-w

Woodward, G.; Gessner, M.O.; Giller, P.S.; Gulis, V.; Hladyz, S.; Lecerf, A.; Malmqvist, B.; McKie, B.G.; Tiegs, S.D.; Carris, H. Continental-scale effects of nutrient pollution on stream ecosystem functioning. *Science* **2012**, 336, 1438-40.

Chapter 5 – Conclusions

The cattle exclusion conservation easements at Horse Creek were installed with the intention of improving water quality in the stream and in the recipient lake, Grand Lake o' the Cherokees. Stream health is inexorably linked to land use in the watershed, and impacts due to agriculture, urbanization, and other anthropogenic stresses accelerate the degradation of habitat and ecosystem function. Without ecosystem function, streams and riparian zones cannot moderate water quality or water quantity, nor provide adequate habitat for aquatic species. Although the traditional goal of riparian restoration activities, such as cattle exclusion, focus mostly on structural attributes, the ecosystem functional attributes are rarely studied or understood, defeating the purpose of restoration.

The first step in understanding ecosystem functional processes was to characterize the Horse Creek watershed. Land use was dominated by anthropogenic intensification – 89% of the watershed was utilized for crops or for cattle pasture. In pasture lands, riparian and aquatic habitat was poor – vegetation was deforested to the stream edge and livestock increased erosion and denuded banks of supporting vegetation. Within the conservation easement, the impact of previously unmanaged land was still apparent – streambanks were recovering from increased erosion and flow variability was not ideal, but the riparian zone was protected from grazing, allowing grasses and shrubs to establish. In time, these will likely give way to larger trees, increasing streambank stability. Despite their geographic proximity, Fivemile Creek took on a different character than the agriculturally-dominated Horse Creek sites. The land was dominated by deciduous forests, and the stream exhibited increased flow variability, a dominance of cobble substrate, and lesser concentrations of nutrients. Although streambank erosion was high due to flash floods, the riparian zone was robust, and the Fivemile Creek habitat assessment scored well in comparison to Horse Creek as a result.

Next, ecosystem structure was evaluated by identifying biotic assemblages in the stream systems. Fish and macroinvertebrates were strong indicators of water quality and habitat conditions in the stream and the watershed – their distribution and abundance were used to infer streams that are stressed due to anthropogenic or ecosystem disturbances. It was no surprise that Fivemile Creek exhibited the greatest metrics for both fish and macroinvertebrate assemblages, with greater scores for diversity, species richness, and low pollution tolerance. Horse Creek East, the site in conservation, scored relatively well for fish assemblages, but poorly for macroinvertebrate assemblages. Outside of the conservation easement, Horse Creek North scored very poorly for both indicators. Correlations were drawn between biotic assemblages and watershed land use intensification, especially developed land. Strong correlations were also drawn between biotic indices and habitat metrics, including riparian vegetative zone width and stream flow velocity and depth regime.

Remote sensing was used to quantify the impact of cattle exclusion fencing at Horse Creek on riparian structure. Digital surface models of the canopy structure in the conservation easement were generated, and results indicated that at each of the three conservation easement sites, aboveground biomass increased over a two-year span between 2020 and 2022 by approximately 2%. Two of the three fenced-in areas in the Horse Creek conservation easement exhibited increases in NDVI over the two-year span. However, one of the sites in the southern portion of the easement surrounds a small tributary that went dry due to drought conditions early in the summer. As such, plant stress in the southern conservation easement increased, and NDVI values decreased by approximately 5% compared to the 2020 values.

Net primary productivity was evaluated using the open diel oxygen method. Sites had variable NPP response throughout the study period, and no significant relationships could be drawn between NPP and water quality, habitat metrics, or land use characteristics. Decomposition rates of cotton strips were lowest at Fivemile Creek, the reference reach, as predicted in the hypothesis. Horse Creek East, within the conservation easement, exhibited the next lowest rates of cotton strip decomposition, followed by the two non-conservation sites at Horse Creek. In each case, rates of decomposition strongly correlated with water quality parameters such as temperature, nitrate concentrations, and reactive phosphorous concentrations. Decomposition also strongly and positively correlated with hay and pasture land use in the watershed, and increases in decomposition rates were correlated with decreased riparian vegetative zone cover.

Positive correlations occurred between metrics such as fish and macroinvertebrate assemblage indices, ecosystem productivity, and organic matter decomposition with decreases in agricultural land use, increased riparian vegetative zone width and stream flow variability, decreased temperature, and decreased developed and urbanized land. Conversely, drivers of ecosystem structural and functional degradation included increased concentrations of nutrients in water, increased temperature, increased agricultural intensity, and increased developed land.

Restoration of the riparian and aquatic ecosystems at Horse Creek through the use of cattle exclusion fencing appears to be making a positive impact on structural and functional indicators. These exclusions mitigate the drivers of ecosystem degradation by increasing riparian vegetative zone width, and decreasing agricultural land use, water temperature, and the loads of nutrients from runoff into the streams. By incorporating functional ecosystem indicators into this study, the body of evidence supporting the establishment of cattle exclusion fences to conserve and restore riparian habitat was improved. Future assessments at Horse Creek should continue to incorporate indicators of ecosystem function.

Appendix A: Habitat Assessment Score Sheets

Site Name:	Horse Creek East (Treatment)	Site Date:	June 11 2022
Start Point:	400m upstream of sample point	Site Time:	815
End Point:	36º40'45.12"N, 94º55'21.24"W	Sinuosity:	1.19
Investigators:	DMW SD	Direction:	Downstream

Distance	Depth (m)			Width (m)		Substrate (%)									Habitat				In-Stream Cover (% Area)												
	L 1/4	C	R 1/4	Water	Bank	SI&C	Sand	GVL	CBL	BLD	BRK	POM	HPC	Sum	Riffle	Run	Pool	Dry	UCB	LWD	SWD	RTS	BRL	SAV	EAV	TV	CB&G	EMB	CAN	PtB	D/S
20	0.4	0.6	0.8	11	21	0	10	20	10	0	60	0	0	100		x			0	1	0	0	5	0	10	0	0	0	50	0	60
40	0.1	0.1	0.1	16	21	0	30	60	10	0	0	0	0	100	x				0	0	0	0	0	0	5	0	1	10	25	5	0
60	0.2	0	0.2	17	19	0	30	30	10	0	30	0	0	100			x		2	1	0	1	0	0	3	1	0	20	30	20	0
80	0.4	0.5	0.1	16	18	0	10	20	0	0	70	0	0	100			x		3	5	1	0	2	0	4	4	0	5	10	0	20
100	0.5	0.4	0.1	19	20	5	15	10	10	1	54	5	0	100		x			1	0	5	1	3	0	0	3	1	5	15	0	20
120	0.2	0.3	0.3	13	16	0	5	20	5	0	70	0	0	100		x			1	0	2	2	10	0	5	0	0	0	25	0	50
140	0.2	0.2	0.2	13	18	0	5	10	5	0	80	0	0	100			x		1	0	0	3	25	0	5	0	0	0	70	0	60
160	0.4	0.4	0.3	14	18	0	5	5	0	0	90	0	0	100		x			2	0	0	3	40	0	5	1	0	0	50	0	60
180	0.2	0.2	0.3	13	16	0	3	2	5	0	90	0	0	100		x			0	0	1	0	40	0	5	0	0	0	35	0	60
200	0.5	0.5	0.3	14	19	0	5	5	10	0	80	0	0	100		x			1	0	1	2	35	0	3	0	0	0	30	0	50
220	0.4	0.4	0.1	15	20	5	10	20	5	0	60	0	0	100		x			1	1	0	2	30	0	2	0	0	10	45	0	40
240	0.2	0.3	0.1	12	22	0	10	20	15	5	50	0	0	100			x		0	0	0	1	10	0	1	0	2	10	30	0	20
260	0.5	0.7	0.7	12	18	0	10	15	20	5	50	0	0	100			x		1	0	0	2	10	0	1	2	2	10	25	0	10
280	0.6	0.8	0.7	12	22	0	5	15	10	0	70	0	0	100		x			0	0	0	0	20	0	0	2	0	5	70	0	10
300	0.9	1	0.8	12	22	0	5	4	0	0	90	1	0	100		x			3	1	0	1	25	0	0	1	0	0	75	0	60
320	0.6	0	0.2	19	25	0	10	15	15	40	20	0	0	100			x		2	2	0	1	5	0	0	1	5	5	40	5	0
340	0.6	0.1	0	17	22	0	15	20	30	20	15	0	0	100			x		0	10	3	2	0	0	0	1	1	5	40	40	10
360	0.3	0	0.3	11	23	0	10	20	25	5	40	0	0	100			x		0	5	1	0	15	0	3	0	2	2	40	10	15
380	0.4	0.5	0.5	24	28	10	15	25	25	5	20	0	0	100			x		0	1	0	0	2	0	15	2	2	10	30	0	5
400	0.5	0.7	0.6	23	27	5	20	30	15	5	20	5	0	100		x			0	2	1	1	0	0	5	0	0	20	15	0	5

Site Name:	Horse Creek East (Treatment)	Site Date:	June 11 2022
Start Point:	400m upstream of sample point	Site Time:	815
End Point:	36º40'45.12"N, 94º55'21.24"W	Sinuosity:	1.19
Investigators:	DMW SD	Direction:	Downstream

Distance	Bank Veg %		Dominant Veg		HT of Bank (m)		HT Eroded (m)		Length Eroded (m)		° Slope		Rip Width (m)		Rip Cond		Cattle			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	% Trampled	# Cow Pies	# Trails	Avg Width
20	40	75	G+S	M	0.6	2.5	0.6	0.6	20	20	5	15	30	10	2A	2B				
40	90	20	M	G	1.5	3	0.8	3	5	16	80	75	30	15	2A	1B				
60	80	10	T	G	2	3	0.5	3	10	20	90	75	30	7	2B	1B				
80	85	5	M	G	2	3	0.4	2.5	15	20	90	70	30	7	2A	2B				
100	90	20	M	G+S	2	2.5	0.3	2	15	20	75	70	30	10	1A	2A				
120	95	75	M	M	3	2.5	0.2	0.5	3	14	60	50	30	15	1A	2A				
140	95	70	M	M	3.5	2	0.2	0.4	2	16	45	35	30	15	1A	2A				
160	95	70	M	S	3	2	0.2	1	2	15	35	25	30	15	1A	2B				
180	100	75	M	M	2.5	1.5	0.3	0.7	1	12	45	40	30	20	1A	2A				
200	95	80	G+T	M	2	2	0.3	0.5	2	17	50	25	30	20	1A	2A				
220	90	75	M	M	2	2	0.4	0.6	3	18	30	45	30	10	1B	2A				
240	100	80	M	M	2	1.5	0	0.4	0	10	5	10	30	10	2A	2B				
260	60	70	G	M	1.5	1.5	1.5	0.5	10	15	5	60	30	15	2B	2B				
280	30	50	G	M	1.5	4	1	1.5	19	19	3	50	30	20	2C	1B				
300	75	30	G	M	1	4	0.4	1.5	5	19	20	35	20	20	2B	1B				
320	80	70	S	S+T	2	3	0.5	1	8	18	70	60	15	15	2B	2B				
340	85	70	M	M	3	2.5	0.5	0.7	5	20	60	40	15	15	2A	2A				
360	95	80	M	G	2.5	2	0.2	0.5	1	18	10	25	15	20	2A	2B				
380	100	80	M	G	3	2	0	1.5	0	5	45	30	15	15	2A	2B				
400	100	40	M	G	4	2.5	0	1.5	0	15	70	80	15	15	2A	2A				

Site Name:	Horse Creek North (Control 1)	Site Date:	6/12/2022
Start Point:	36º41'19.49"N, 94º56'22.96"W	Site Time:	800
End Point:	400m upstream	Sinuosity:	1.02
Investigators	DMW SD	Direction:	Upstream

Distance	Depth (m)			Width (m)		Substrate (%)									Habitat				In-Stream Cover (% Area)									EMB	CAN	PtB	D/S
	L 1/4	C	R 1/4	Water	Bank	SI&C	Sand	GVL	CBL	BLD	BRK	POM	HPC	Sum	Riffle	Run	Pool	Dry	UCB	LWD	SWD	RTS	BRL	SAV	EAV	TV	CB&G				
20	0.5	0.7	0.6	16	19	20	25	30	10	0	10	5	0	100			x		1	2	0	1	0	0	10	0	0	30	15	0	0
40	0.6	0.7	0.7	15	20	25	25	20	5	0	20	5	0	100			x		0	0	0	1	0	0	8	0	0	40	5	0	0
60	0.5	0.7	0.6	16	20	25	25	20	5	0	20	5	0	100			x		0	0	1	0	0	0	5	0	0	30	5	0	0
80	0.5	0.6	0.5	16	18	25	25	20	5	0	20	5	0	100			x		0	5	2	0	0	0	3	1	0	40	35	0	0
100	0.4	0.5	0.5	16	18	15	15	50	10	2	0	8	0	100			x		0	1	1	0	0	0	3	1	0	25	40	0	0
120	0.4	0.5	0.5	16	19	20	20	40	10	3	0	7	0	100			x		0	2	0	1	0	0	0	0	0	25	40	0	0
140	0.5	0.5	0.5	17	18	25	15	35	15	0	0	10	0	100			x		0	2	0	0	0	0	1	1	0	40	30	0	0
160	0.4	0.5	0.3	15	16	15	15	60	5	0	0	5	0	100			x		0	2	0	0	0	0	30	0	0	20	60	0	0
180	0.3	0.4	0.3	17	19	15	15	60	5	0	0	5	0	100			x		0	1	0	0	0	0	20	0	0	20	40	0	0
200	0.5	0.3	0.3	17	18	15	15	50	15	0	0	5	0	100			x		1	0	2	0	0	0	5	0	0	15	30	0	0
220	0.4	0.3	0.3	15	17	20	15	40	20	0	0	5	0	100			x		2	0	4	0	0	0	5	0	0	30	60	0	0
240	0.4	0.4	0.4	15	16	20	15	40	20	0	0	5	0	100			x		0	0	1	0	0	0	3	1	0	20	20	0	0
260	0.5	0.4	0.4	15	16	20	18	40	20	0	0	2	0	100			x		2	1	1	2	0	0	0	0	0	30	40	0	0
280	0.3	0.3	0.3	15	16	15	20	40	20	3	0	2	0	100			x		2	2	0	0	0	0	0	2	0	20	20	0	0
300	0.3	0.3	0.3	14	15	15	20	40	20	5	0	0	0	100			x		1	1	1	1	0	0	0	0	0	20	40	0	0
320	0.3	0.4	0.4	13	14	15	20	45	20	0	0	0	0	100			x		0	1	0	0	0	0	0	0	0	25	15	0	0
340	0.3	0.3	0.3	11	16	15	20	45	20	0	0	0	0	100			x		0	0	2	2	0	0	0	0	0	20	20	0	0
360	0.1	0.1	0	11	16	20	29	40	10	1	0	0	0	100			x		0	0	1	1	0	0	0	0	0	30	15	0	0
380	0.2	0.2	0.2	13	15	20	30	40	10	0	0	0	0	100			x		0	0	0	0	0	0	0	0	0	30	5	0	0
400	0.2	0.3	0.2	12	16	15	35	40	10	0	0	0	0	100			x		0	0	0	0	0	0	0	0	0	30	60	0	0

Site Name:	Horse Creek North (Control 1)	Site Date:	6/12/2022	
Start Point:	36º41'19.49"N, 94º56'22.96"W	Site Time:	800	
End Point:	400m upstream	Sinuosity:	1.02	
Investigators:	DMW SD	Direction:	Upstream	

Distance	Bank Veg %		Dominant Veg		HT of Bank (m)		HT Eroded (m)		Length Eroded (m)		° Slope		Rip Width (m)		Rip Cond		Cattle			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	% Trampled	# Cow Pies	# Trails	Avg Width
20	100	75	M	M	1.5	1.5	0	0.5	0	12	40	65	25	15	1B	1C	x	x	x	x
40	90	70	M	G	1.5	2	0.2	0.7	3	16	30	55	0	0	2B	2C	0	0	0	x
60	90	60	M	G	1.5	1.5	0.2	1	2	16	30	50	0	0	2B	2B	20	0	1	0.4
80	70	70	G+T	G	1	1.5	0.5	0.8	6	12	40	40	0	0	2B	2B	0	0	1	0.3
100	80	60	G+T	G	1	1	0.5	0.8	5	16	50	60	0	0	2B	2C	0	0	2	0.4
120	60	40	T	G	1	1	0.5	0.9	11	17	65	60	0	0	2B	2C	0	0	2	0.5
140	75	50	M	G	1.5	1	0.4	0.6	10	15	80	60	0	0	2B	2B	10	0	1	0.3
160	50	85	T	G	2	1	1	0.2	18	4	90	45	0	0	2B	2B	0	0	1	0.3
180	70	70	T	G	2	1	0.5	0.3	7	14	90	60	0	0	2A	2B	0	0	1	0.3
200	65	30	M	G	2	1	0.5	0.8	6	16	90	70	0	0	2B	2B	0	0	2	1
220	50	20	T	G	2.5	1	0.7	1	10	18	85	20	0	0	2B	2C	25	0	4	1.5
240	70	60	T+S	G	2	1	0.4	0.3	12	15	80	50	0	0	2A	2B	10	0	0	0
260	65	60	M	T+G	1.5	1.5	0.5	0.8	7	14	85	60	0	0	2B	2B	20	0	0	0
280	60	75	T	G	1.5	1	0.8	0.5	10	5	80	55	0	0	2B	2B	0	0	2	1
300	60	50	M	T+G	1.5	1	0.6	0.8	14	10	80	55	0	0	2B	2C	0	0	2	0.5
320	80	65	G	G	1.5	1.5	0.3	0.4	10	12	75	70	0	0	2B	2B	0	0	0	x
340	50	70	T	G	1.5	1	0.5	0.3	7	14	80	50	0	0	2B	2C	0	0	3	0.3
360	80	55	T	G	1.5	1	0.3	0.5	6	10	70	10	0	0	2B	2C	60	3	1	10
380	25	25	G	G	1.5	1.5	1.5	1.5	8	12	10	5	0	0	2C	2D	15	1	5	2
400	60	50	M	T+G	1.5	1.5	0.6	0.8	7	10	30	25	0	0	2C	2C	40	1	5	1

Site Name:	Little Horse Creek (Control 2)	Site Date:	6/11/2022
Start Point:	36º41'8.89"N, 94º54'48.21"W	Site Time:	1340
End Point:	400m upstream	Sinuosity:	1.26
Investigators	DMW SD	Direction:	Upstream

	Depth (m)			Width (m)		Substrate (%)									Habitat				In-Stream Cover (% Area)													Bank Veg %	
Distance	L 1/4	C	R 1/4	Water	Bank	SI&C	Sand	GVL	CBL	BLD	BRK	POM	HPC	Sum	Riffle	Run	Pool	Dry	UCB	LWD	SWD	RTS	BRL	SAV	EAV	TV	CB&G	EMB	CAN	PtB	D/S	Left	Right
20	0.3	0.5	0.3	12	13	0	10	40	30	15	5	0	0	100		x			0	5	5	0	0	0	1	0	1	15	65	0	0	80	80
40	0.4	0.3	0.2	11	15	0	10	20	40	30	0	0	0	100		x			0	3	2	0	0	0	0	0	2	5	35	0	0	40	70
60	0.5	0.8	0.5	11	12	0	5	5	25	5	60	0	0	100			x		0	0	1	1	2	0	0	0	2	5	75	0	30	20	50
80	0.4	0.3	0.5	9	12	0	20	10	30	20	20	0	0	100			x		2	0	4	5	2	0	0	0	2	20	75	0	10	70	50
100	0.5	0.6	0.3	9	13	0	5	10	40	25	20	0	0	100			x		2	0	0	3	5	0	0	0	1	10	60	1	5	75	60
120	0.5	0.6	0.5	9	12	0	5	5	0	0	90	0	0	100			x		0	0	0	1	20	0	0	0	1	0	80	0	40	65	70
140	0.5	0.7	0.5	9	15	0	5	0	0	0	95	0	0	100		x			1	0	0	0	40	0	2	0	0	0	70	0	40	25	60
160	0.3	0.4	0.3	9	14	0	5	10	5	0	80	0	0	100		x			0	0	0	0	20	0	5	0	0	0	50	4	20	75	50
180	0.1	0.1	0.1	7	20	0	0	0	5	5	90	0	0	100	x				1	0	0	3	25	0	2	0	3	0	70	0	50	65	60
200	0.7	0.7	0.7	10	15	0	0	5	5	0	90	0	0	100			x		0	1	0	4	20	0	0	0	0	0	80	2	20	50	80
220	0.6	0.5	0.5	8	12	0	5	10	6	0	75	1	0	97		x			1	0	1	3	40	0	7	0	0	0	60	0	10	55	85
240	0.1	0.1	0.1	10	13	0	5	5	10	0	80	0	0	100	x				1	0	1	1	40	0	5	0	3	5	80	0	10	20	90
260	0.4	0.3	0.3	8	14	0	10	10	20	0	60	0	0	100		x			0	0	0	0	20	0	5	0	0	0	75	8	10	25	90
280	0.2	0.2	0.2	10	15	0	3	20	7	0	70	0	0	100		x			0	0	0	2	10	0	2	0	0	0	80	0	20	70	60
300	0.2	0.5	0.5	6	13	0	10	20	10	0	60	0	0	100		x			2	0	0	4	30	0	5	0	2	5	50	0	10	60	20
320														0																			
340														0																			
360														0																			
380														0																			
400														0																			

Notes: Tributary @ 300m, could not continue due to cattle fence

Site Name:	Little Horse Creek (Control 2)	Site Date: 6/11/2022
Start Point:	36º41'8.89"N, 94º54'48.21"W	Site Time: 1340
End Point:	400m upstream	Sinuosity: 1.26
Investigators:	DMW SD	Direction: Upstream

Distance	Dominant Veg		HT of Bank (m)		HT Eroded (m)		Length Eroded (m)		° Slope		Rip Width (m)		Rip Cond		Cattle			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	% Trampled	# Cow Pies	# Trails	Avg Width
20	G	G	1	1	0.5	0.2	10	6	40	10	20	30	1B	1A				
40	G+T	G+T	2	1.5	2	1	10	5	50	30	20	30	1B	1A				
60	M	M	3	2	2.5	1	18	14	65	70	20	30	1B	1A				
80	G	G+T	2.5	2	1	0.5	12	14	60	40	25	30	1B	1A				
100	G	G+T	2	1.5	0.5	1	5	15	50	75	30	30	1B	1A				
120	S	G	2	3	1.5	0.6	14	14	45	30	30	30	1A	1A				
140	S	G	2	1.5	2	1	18	16	35	60	30	30	1A	1A				
160	M	G	1.5	1.5	0.5	1	5	15	30	30	30	30	1A	1A				
180	G	G	2	2.5	0.8	0.6	5	10	5	25	30	30	1A	1A				
200	G	T	2	3	0.8	0.5	10	6	5	45	30	30	1A	1A				
220	M	G+T	2.5	2	0.6	0.2	6	3	35	15	30	30	1A	1A				
240	T	G	3	1.5	2	0.4	18	3	70	5	30	30	1A	1B				
260	G+T	G+T	2	1.5	1.5	0.5	20	2	80	5	30	30	1A	1A				
280	G+T	G+T	1.5	1.5	0.8	0.5	14	10	20	10	30	30	1A	1A				
300	G	M	1	2	0.2	1.5	8	16	2	80	30	30	1B	1A				
320																		
340																		
360																		
380																		
400																		

Site Name:	Fivemile (Reference)	Site Date:	6/12/2022
Start Point:	36º59'17.61"N, 94º38'43.49"W	Site Time:	1330
End Point:	400m upstream	Sinuosity:	1.24
Investigators	DMW SD	Direction:	Upstream

	Depth (m)			Width (m)		Substrate (%)									Habitat				In-Stream Cover (% Area)												
Distance	L 1/4	C	R 1/4	Water	Bank	SI&C	Sand	GVL	CBL	BLD	BRK	POM	HPC	Sum	Riffle	Run	Pool	Dry	UCB	LWD	SWD	RTS	BRL	SAV	EAV	TV	CB&G	EMB	CAN	PtB	D/S
20	0.2	0.1	0.4	13	23	0	15	25	50	10	0	0	0	100	x				0	0	0	0	0	0	0	0	10	10	10	40	0
40	0.4	0.4	0.2	8	26	0	15	25	50	10	0	0	0	100		x			0	0	0	0	0	0	0	0	5	15	40	40	0
60	0	0.2	0.5	21	22	0	15	55	25	5	0	0	0	100	x				1	0	0	0	0	0	0	0	10	5	20	20	0
80	0.4	0.5	1.1	11	17	0	20	65	15	0	0	0	0	100		x			2	0	0	2	2	0	0	3	0	10	50	15	0
100	0.2	0.4	0.3	15	20	0	10	50	30	5	5	0	0	100		x			1	0	0	2	15	0	0	0	0	5	30	20	0
120	0.3	0.4	0.2	11	23	0	10	10	10	0	70	0	0	100	x				1	0	1	0	20	0	0	0	5	0	25	30	0
140	0.2	0.3	0.2	10	21	0	5	15	5	0	70	0	5	100	x				0	0	0	0	20	0	0	0	5	0	30	30	0
160	0	0.2	0.1	22	25	0	25	25	30	20	0	0	0	100	x				0	0	0	0	0	0	0	0	10	0	10	40	0
180	0	0	0.1	32	35	0	15	30	40	15	0	0	0	100	x				0	0	0	0	0	0	0	0	10	5	5	50	0
200	0.4	0.5	0.3	14	36	0	20	50	25	5	0	0	0	100		x			0	0	0	0	0	0	0	0	5	15	5	65	0
220	0.4	0.9	1.1	11	22	0	15	60	20	3	0	2	0	100			x		0	0	3	1	0	1	0	5	0	5	20	60	0
240	0.4	1.4	0.4	14	38	0	20	60	16	2	0	2	0	100			x		0	3	8	1	0	5	0	0	0	5	20	60	0
260	0.3	0.4	0.8	9	35	0	20	60	16	4	0	0	0	100			x		1	5	2	3	0	1	0	0	0	10	30	60	0
280	0.2	0.6	0.7	6	40	0	20	70	10	0	0	0	0	100		x			3	0	0	5	0	2	0	20	0	5	20	75	0
300	0.2	0.1	0.2	14	37	0	20	35	40	5	0	0	0	100	x				0	0	0	0	0	0	0	0	0	10	15	75	0
320	0.1	0.2	0.2	9	34	0	20	35	40	5	0	0	0	100	x				0	0	1	0	0	0	0	0	0	10	10	70	0
340	0.5	0.5	0.4	10	50	0	40	30	30	0	0	0	0	100		x			0	0	0	0	0	0	0	0	0	15	30	50	0
360	0.4	0.5	0.3	14	35	0	15	55	25	5	0	0	0	100			x		2	0	0	3	0	0	0	0	0	15	25	70	0
380	0.9	0.8	0.4	11	61	0	20	60	15	5	0	0	0	100			x		0	0	0	3	0	0	0	0	0	5	35	85	0
400	0.8	1	0.4	11	52	0	20	60	15	0	0	0	5	100			x		0	1	0	1	0	0	0	0	0	5	50	80	0

Site Name:	Fivemile (Reference)	Site Date:	6/12/2022
Start Point:	36º59'17.61"N, 94º38'43.49"W	Site Time:	1330
End Point:	400m upstream	Sinuosity:	1.24
Investigators:	DMW SD	Direction:	Upstream

Distance	Bank Veg %		Dominant Veg		HT of Bank (m)		HT Eroded (m)		Length Eroded (m)		° Slope		Rip Width (m)		Rip Cond		Cattle			
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	% Trampled	# Cow Pies	# Trails	Avg Width
20	20	0	M	G	2.5	3	2	3	16	20	10	30	30	30	2A	2B				
40	25	10	G+T	G	2.5	3	1.5	2.5	16	20	30	50	30	30	2A	2A				
60	10	60	G+T	G	3	1	2.5	0.5	18	15	90	5	30	30	2A	2A				
80	5	70	G+T	G+T	3	2	2.5	0.4	20	8	90	15	30	30	2A	2A				
100	30	30	G+T	G+T	3	2.5	2.5	2	10	10	75	60	30	30	2A	2A				
120	45	20	M	G	3	2	2.5	2	8	18	80	25	30	30	2A	2A				
140	25	5	G+T	G	2.5	1.5	2	1.5	18	20	80	10	30	30	2A	1B				
160	5	0	G	G	3	1.5	1.5	1.5	20	20	90	20	30	30	2A	1B				
180	5	0	G	G	2.5	2	2	2	18	20	70	30	30	30	2A	1B				
200	30	5	G	T	2	1.5	1.5	1.5	16	20	80	10	30	30	2A	1A				
220	60	30	G	T	2	1.5	1	1.5	12	18	70	40	30	30	2A	1A				
240	60	15	G	T	2	1	1.5	1	10	15	65	25	30	30	2A	1A				
260	60	20	M	T	2	1.5	1.5	1.5	6	16	60	60	30	30	2A	2A				
280	90	10	M	T	2	1.5	0	1	0	18	40	50	30	30	2A	2A				
300	100	10	M	G	2	1.5	0	1	0	18	30	40	30	30	2A	2A				
320	100	10	M	G	2	2	0	1.5	0	20	30	60	30	30	2A	2A				
340	95	20	M	M	2	3	0	2.5	0	18	20	75	30	30	2A	2A				
360	60	50	G+T	M	2	2.5	1.5	1.5	4	12	50	60	30	30	2A	2A				
380	5	50	G	M	3	2	2	1	20	14	80	70	30	30	2A	2A				
400	15	60	M	M	3	3	2.5	2	20	9	90	60	30	30	2A	2A				

Appendix B: GPP, R, NPP Summary Table

Treatment (HCE)	**GPP**	**R**	**NPP**
Feb	824.2	-473	351.2
Apr	3232.8	-2155	1077.8
May	6314.3	-4888.1	1426.3
June	7072.9	-4633.2	2439.8
July	4986.9	-4388.8	598.1
Aug	4439.3	-3416.4	1032.9
Sept	2382.5	-2417.8	-35.3

Control 1 (HCN)	**GPP**	**R**	**NPP**
Feb	1526.6	-981.1	545.5
Apr	2418.1	-1366.5	1051.5
May	2022.7	-1401.6	621.1
June	1355.5	-552.6	802.9
July	3039.9	-2698.1	341.8
Aug	5913.3	-3819.4	2094
Sept	3177.1	-2733.1	444

Control 2 (LHC)	**GPP**	**R**	**NPP**
Feb	361.4	-173	188.4
Apr	1511.3	-941.7	569.6
May	103.5	-262.8	-159.3
June	1301.4	-700.8	600.6

Reference (5MI)	**GPP**	**R**	**NPP**
Apr	275.1	-325.9	-50.8
May	695.5	-565	130.5
June	860.3	-473	387.3
July	850.1	-525.6	324.5
Aug	839.9	-565	274.9
Sept	924.3	-578.2	346.2

Appendix C: Statistics Outputs from SPSS

Kruskal-Wallis: NPP across Site

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distribution of Net Primary Productivity is the same across categories of Site.	Independent-Samples Kruskal-Wallis Test	.031	Reject the null hypothesis.

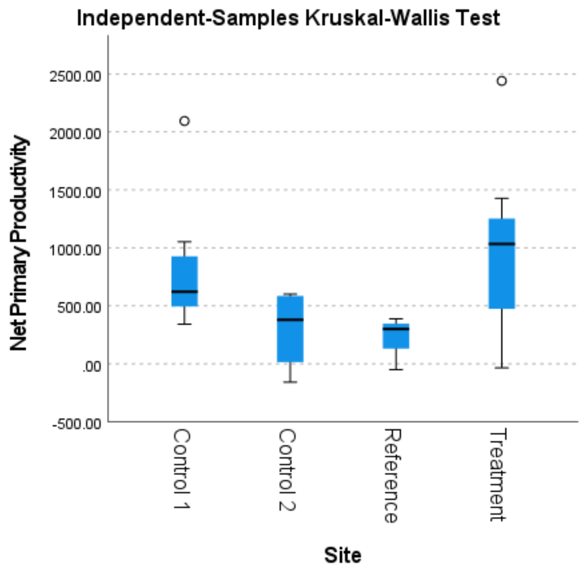
a. The significance level is .050.

b. Asymptotic significance is displayed.

Independent-Samples Kruskal-Wallis Test Summary

Total N	24
Test Statistic	8.884[a]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.031

a. The test statistic is adjusted for ties.



Pairwise Comparisons of Site

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Reference-Control 2	2.500	4.564	.548	.584	1.000
Reference-Control 1	9.357	3.934	2.379	.017	.104
Reference-Treatment	-9.786	3.934	-2.487	.013	.077
Control 2-Control 1	6.857	4.432	1.547	.122	.731
Control 2-Treatment	-7.286	4.432	-1.644	.100	.601
Control 1-Treatment	-.429	3.780	-.113	.910	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Kruskal-Wallis: CTSL Rate across Site

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distribution of CTSL Rate (%/day) is the same across categories of Site.	Independent-Samples Kruskal-Wallis Test	.034	Reject the null hypothesis.

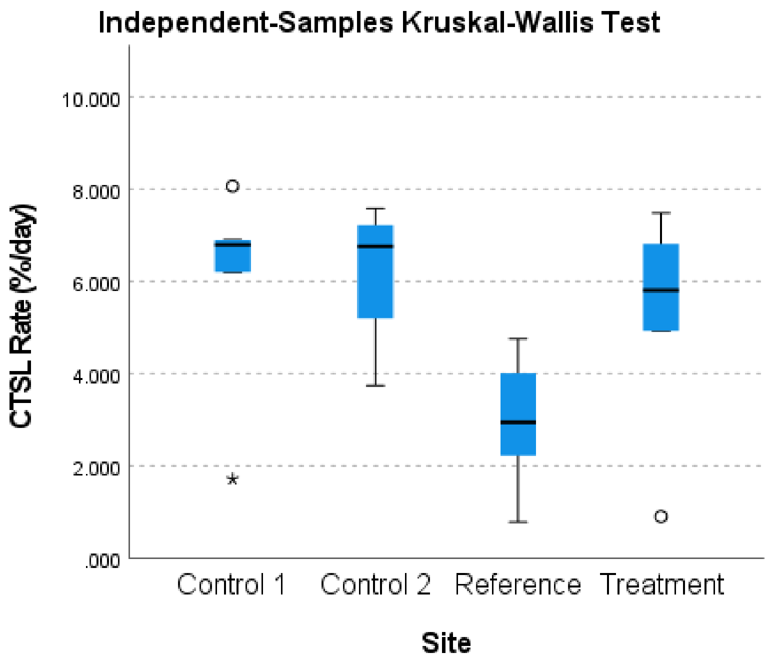
a. The significance level is .050.

b. Asymptotic significance is displayed.

Independent-Samples Kruskal-Wallis Test Summary

Total N	23
Test Statistic	8.676[a]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.034

a. The test statistic is adjusted for ties.



Pairwise Comparisons of Site

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Reference-Treatment	-6.667	3.773	-1.767	.077	.464
Reference-Control 2	9.750	4.251	2.294	.022	.131
Reference-Control 1	9.833	3.773	2.606	.009	.055
Treatment-Control 2	3.083	4.378	.704	.481	1.000
Treatment-Control 1	3.167	3.916	.809	.419	1.000
Control 2-Control 1	.083	4.378	.019	.985	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Stepwise Regression: NPP vs. Temperature

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Mean Temperature[b]	.	Enter

a. Dependent Variable: Net Primary Productivity

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.218[a]	.048	.004	629.71395

a. Predictors: (Constant), Mean Temperature

b. Dependent Variable: Net Primary Productivity

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	436578.694	1	436578.694	1.101	.305[b]
	Residual	8723872.392	22	396539.654		
	Total	9160451.086	23			

a. Dependent Variable: Net Primary Productivity

b. Predictors: (Constant), Mean Temperature

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	217.751	424.097		.513	.613
	Mean Temperature	19.772	18.844	.218	1.049	.305

a. Dependent Variable: Net Primary Productivity

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	354.5763	802.2248	641.8125	137.77403	24
Residual	-885.59857	1700.05615	.00000	615.87239	24
Std. Predicted Value	-2.085	1.164	.000	1.000	24
Std. Residual	-1.406	2.700	.000	.978	24

a. Dependent Variable: Net Primary Productivity

Stepwise Regression: NPP vs. Water Quality Parameters

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	SO4, Cl, NO2, NO3+NO2, PO4[b]	.	Enter

a. Dependent Variable: Net Primary Productivity

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.437[a]	.191	-.033	641.49906

a. Predictors: (Constant), SO4, Cl, NO2, NO3+NO2, PO4

b. Dependent Variable: Net Primary Productivity

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1753072.264	5	350614.453	.852	.531[b]
	Residual	7407378.822	18	411521.046		
	Total	9160451.086	23			

a. Dependent Variable: Net Primary Productivity

b. Predictors: (Constant), SO4, Cl, NO2, NO3+NO2, PO4

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	278.236	306.120		.909	.375
	NO3+NO2	-119.566	319.564	-.106	-.374	.713
	NO2	5209.692	5976.793	.268	.872	.395
	PO4	804.521	1640.576	.161	.490	.630
	Cl	8.308	6.350	.291	1.308	.207
	SO4	-2.117	8.599	-.078	-.246	.808

a. Dependent Variable: Net Primary Productivity

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	133.4218	1261.3815	641.8125	276.08066	24
Residual	-1015.75665	1910.85217	.00000	567.50326	24
Std. Predicted Value	-1.841	2.244	.000	1.000	24
Std. Residual	-1.583	2.979	.000	.885	24

Stepwise Regression: NPP vs. Land Use Categories

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Emergent Wetlands, Hay/Pasture, Developed, Medium Intensity[b]	.	Enter

a. Dependent Variable: Net Primary Productivity

b. Tolerance = .000 limit reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.529[a]	.280	.172	574.32340

a. Predictors: (Constant), Emergent Wetlands, Hay/Pasture, Developed, Medium Intensity

b. Dependent Variable: Net Primary Productivity

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2563503.731	3	854501.244	2.591	.081[b]
	Residual	6596947.355	20	329847.368		
	Total	9160451.086	23			

a. Dependent Variable: Net Primary Productivity

b. Predictors: (Constant), Emergent Wetlands, Hay/Pasture, Developed, Medium Intensity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1022.412	1950.455		.524	.606
	Developed, Medium Intensity	-564.187	1256.802	-.119	-.449	.658
	Hay/Pasture	4.485	11.600	.092	.387	.703
	Emergent Wetlands	5364.594	2063.278	.567	2.600	.017

a. Dependent Variable: Net Primary Productivity

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Open Water	.[b]	.	.	.	.000
	Developed, Open Land	.[b]	.	.	.	.000
	Developed, Low Intensity	.[b]	.	.	.	.000
	Developed, High Intensity	.[b]	.	.	.	.000
	Barren Land	.[b]	.	.	.	.000
	Deciduous Forest	.[b]	.	.	.	.000
	Mixed Forest	.[b]	.	.	.	.000
	Shrub/Scrub	.[b]	.	.	.	.000
	Herbaceous	.[b]	.	.	.	.000
	Cultivated Crops	.[b]	.	.	.	.000
	Woody Wetlands	.[b]	.	.	.	.000

a. Dependent Variable: Net Primary Productivity

b. Predictors in the Model: (Constant), Emergent Wetlands, Hay/Pasture, Developed, Medium Intensity

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	235.4333	984.4000	641.8125	333.85129	24
Residual	-1019.70001	1455.40002	.00000	535.55933	24
Std. Predicted Value	-1.217	1.026	.000	1.000	24
Std. Residual	-1.775	2.534	.000	.933	24

a. Dependent Variable: Net Primary Productivity

Stepwise Regression: NPP vs. Habitat Assessment

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection[b]	.	Enter

a. Dependent Variable: Net Primary Productivity

b. Tolerance = .000 limit reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.529[a]	.280	.172	574.32340

a. Predictors: (Constant), Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection

b. Dependent Variable: Net Primary Productivity

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2563503.731	3	854501.244	2.591	.081[b]
	Residual	6596947.355	20	329847.368		
	Total	9160451.086	23			

a. Dependent Variable: Net Primary Productivity

b. Predictors: (Constant), Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-2911.303	2559.789		-1.137	.269
	Pool Substrate	108.485	92.188	.660	1.177	.253
	Bank Vegetative Protection	236.797	133.168	1.020	1.778	.091
	Riparian Vegetative Zone Width	10.662	26.243	.140	.406	.689

a. Dependent Variable: Net Primary Productivity

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Available Cover	.[b]	.	.	.	.000
	Embeddedness	.[b]	.	.	.	.000
	Velocity/Depth Regime	.[b]	.	.	.	.000
	Pool Variability	.[b]	.	.	.	.000
	Sediment Deposition	.[b]	.	.	.	.000
	Channel Flow Status	.[b]	.	.	.	.000
	Channel Alteration	.[b]	.	.	.	.000
	Frequency of Riffles	.[b]	.	.	.	.000
	Channel Sinuosity	.[b]	.	.	.	.000
	Bank Stability	.[b]	.	.	.	.000

a. Dependent Variable: Net Primary Productivity

b. Predictors in the Model: (Constant), Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	235.4333	984.4000	641.8125	333.85129	24
Residual	-1019.70001	1455.40002	.00000	535.55933	24
Std. Predicted Value	-1.217	1.026	.000	1.000	24
Std. Residual	-1.775	2.534	.000	.933	24

a. Dependent Variable: Net Primary Productivity

Stepwise Regression: CTSL vs. Temperature

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Mean Temperature[b]	.	Enter

a. Dependent Variable: CTSL Rate (%/day)

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.723[a]	.523	.499	1.512776

a. Predictors: (Constant), Mean Temperature

b. Dependent Variable: CTSL Rate (%/day)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	50.186	1	50.186	21.930	<.001[b]
	Residual	45.770	20	2.288		
	Total	95.956	21			

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors: (Constant), Mean Temperature

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.367	1.070		.343	.735
	Mean Temperature	.218	.047	.723	4.683	<.001

a. Dependent Variable: CTSL Rate (%/day)

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.87568	6.81113	5.14306	1.545908	22
Residual	-2.989305	2.392672	.000000	1.476318	22
Std. Predicted Value	-2.114	1.079	.000	1.000	22
Std. Residual	-1.976	1.582	.000	.976	22

a. Dependent Variable: CTSL Rate (%/day)

Stepwise Regression: CTSL vs. NPP

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Net Primary Productivity[b]	.	Enter

a. Dependent Variable: CTSL Rate (%/day)

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.464[a]	.215	.176	1.940788

a. Predictors: (Constant), Net Primary Productivity

b. Dependent Variable: CTSL Rate (%/day)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20.623	1	20.623	5.475	.030[b]
	Residual	75.333	20	3.767		
	Total	95.956	21			

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors: (Constant), Net Primary Productivity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	4.218	.572		7.369	<.001
	Net Primary Productivity	.002	.001	.464	2.340	.030

a. Dependent Variable: CTSL Rate (%/day)

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.97352	7.95917	5.14306	.990984	22
Residual	-3.856259	2.881479	.000000	1.894016	22
Std. Predicted Value	-1.180	2.842	.000	1.000	22
Std. Residual	-1.987	1.485	.000	.976	22

a. Dependent Variable: CTSL Rate (%/day)

Stepwise Regression: CTSL vs. Water Quality Parameters

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	SO4, Cl, NO2, NO3+NO2, PO4[b]	.	Enter

a. Dependent Variable: CTSL Rate (%/day)

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.780[a]	.608	.492	1.623013

a. Predictors: (Constant), SO4, Cl, NO2, NO3+NO2, PO4

b. Dependent Variable: CTSL Rate (%/day)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	69.392	5	13.878	5.269	.004[b]
	Residual	44.781	17	2.634		
	Total	114.173	22			

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors: (Constant), SO4, Cl, NO2, NO3+NO2, PO4

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.256	.766		5.552	<.001
	NO3+NO2	-1.379	.852	-.309	-1.618	.124
	NO2	22.440	20.941	.267	1.072	.299
	PO4	9.491	5.326	.545	1.782	.093
	Cl	.026	.016	.259	1.596	.129
	SO4	-.046	.027	-.414	-1.678	.112

a. Dependent Variable: CTSL Rate (%/day)

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.49530	7.94197	4.95332	1.776005	23
Residual	-3.386796	2.645642	.000000	1.426708	23
Std. Predicted Value	-1.947	1.683	.000	1.000	23
Std. Residual	-2.087	1.630	.000	.879	23

Stepwise Regression: CTSL vs. Land Use Categories

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Emergent Wetlands, Hay/Pasture, Mixed Forest[b]	.	Enter

a. Dependent Variable: CTSL Rate (%/day)

b. Tolerance = .000 limit reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.603[a]	.363	.263	1.956152

a. Predictors: (Constant), Emergent Wetlands, Hay/Pasture, Mixed Forest

b. Dependent Variable: CTSL Rate (%/day)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	41.469	3	13.823	3.612	.032[b]
	Residual	72.704	19	3.827		
	Total	114.173	22			

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors: (Constant), Emergent Wetlands, Hay/Pasture, Mixed Forest

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.027	5.159		.974	.342
	Mixed Forest	-42.812	45.692	-.251	-.937	.361
	Hay/Pasture	.070	.031	.421	2.218	.039
	Emergent Wetlands	16.009	9.085	.476	1.762	.094

a. Dependent Variable: CTSL Rate (%/day)

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Open Water	.[b]	.	.	.	.000
	Developed, Open Land	.[b]	.	.	.	.000
	Developed, Low Intensity	.[b]	.	.	.	.000
	Developed, Medium Intensity	.[b]	.	.	.	.000
	Developed, High Intensity	.[b]	.	.	.	.000
	Barren Land	.[b]	.	.	.	.000
	Deciduous Forest	.[b]	.	.	.	.000
	Shrub/Scrub	.[b]	.	.	.	.000
	Herbaceous	.[b]	.	.	.	.000
	Cultivated Crops	.[b]	.	.	.	.000
	Woody Wetlands	.[b]	.	.	.	.000

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors in the Model: (Constant), Emergent Wetlands, Hay/Pasture, Mixed Forest

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2.99029	6.20612	4.95332	1.372939	23
Residual	-4.386433	2.191967	.000000	1.817892	23
Std. Predicted Value	-1.430	.913	.000	1.000	23
Std. Residual	-2.242	1.121	.000	.929	23

a. Dependent Variable: CTSL Rate (%/day)

Stepwise Regression: CTSL vs. Habitat Assessment

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection[b]	.	Enter

a. Dependent Variable: CTSL Rate (%/day)

b. Tolerance = .000 limit reached.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.603[a]	.363	.263	1.956152

a. Predictors: (Constant), Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection

b. Dependent Variable: CTSL Rate (%/day)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	41.469	3	13.823	3.612	.032[b]
	Residual	72.704	19	3.827		
	Total	114.173	22			

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors: (Constant), Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	17.222	8.979		1.918	.070
	Pool Substrate	-.524	.319	-.912	-1.645	.116
	Bank Vegetative Protection	-.389	.472	-.484	-.824	.420
	Riparian Vegetative Zone Width	-.177	.094	-.630	-1.888	.074

a. Dependent Variable: CTSL Rate (%/day)

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Available Cover	.[b]	.	.	.	.000
	Embeddedness	.[b]	.	.	.	.000
	Velocity/Depth Regime	.[b]	.	.	.	.000
	Pool Variability	.[b]	.	.	.	.000
	Sediment Deposition	.[b]	.	.	.	.000
	Channel Flow Status	.[b]	.	.	.	.000
	Channel Alteration	.[b]	.	.	.	.000
	Frequency of Riffles	.[b]	.	.	.	.000
	Channel Sinuosity	.[b]	.	.	.	.000
	Bank Stability	.[b]	.	.	.	.000

a. Dependent Variable: CTSL Rate (%/day)

b. Predictors in the Model: (Constant), Riparian Vegetative Zone Width, Pool Substrate, Bank Vegetative Protection

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2.99029	6.20612	4.95332	1.372939	23
Residual	-4.386433	2.191967	.000000	1.817892	23
Std. Predicted Value	-1.430	.913	.000	1.000	23
Std. Residual	-2.242	1.121	.000	.929	23

a. Dependent Variable: CTSL Rate (%/day)

Pearson Correlation Coefficients: Biota vs. Land Use Categories

Metric	Open Water	Developed, Open	Developed, Low	Developed, Medium	Developed, High
Fish Shannon Diversity	-0.838	0.697	-1	-0.998	0.654
Fish Species Richness	-0.998	0.988	-0.818	-0.84	0.977
Fish Evenness	0.015	-0.236	-0.507	-0.472	-0.292
Macroinvertebrate Shannon Diversity	-0.789	0.634	-0.993	-0.988	0.588
Macroinvertebrate Species Richness	-0.996	0.952	-0.896	-0.913	0.933
Macroinvertebrate Species Evenness	0.846	-0.943	0.446	0.481	-0.961
Macroinvertebrate HBI	0.747	-0.581	0.984	0.976	-0.533

Metric	Barren Land	Deciduous Forest	Mixed Forest	Shrub/Scrub	Herbaceous
Fish Shannon Diversity	-0.823	0.698	0.147	0.723	0.694
Fish Species Richness	-0.999	0.988	-0.477	0.993	0.987
Fish Evenness	0.043	-0.234	0.915	-0.2	-0.24
Macroinvertebrate Shannon Diversity	-0.772	0.635	0.229	0.662	0.631
Macroinvertebrate Species Richness	-0.993	0.953	-0.336	0.963	0.951
Macroinvertebrate Species Evenness	0.86	-0.942	0.837	-0.93	-0.944
Macroinvertebrate HBI	0.728	-0.582	-0.294	-0.61	-0.578

Metric	Hay/ Pasture	Cultivated Crops	Woody Wetlands	Emergent Wetlands
Fish Shannon Diversity	-0.564	-0.743	-0.813	-0.697
Fish Species Richness	-0.947	-0.996	-1	-0.988
Fish Evenness	0.398	0.171	0.06	0.236
Macroinvertebrate Shannon Diversity	-0.493	-0.684	-0.761	-0.634
Macroinvertebrate Species Richness	-0.886	-0.97	-0.991	-0.952
Macroinvertebrate Species Evenness	0.986	0.919	0.869	0.943
Macroinvertebrate HBI	0.434	0.633	0.716	0.581

Pearson Correlation Coefficients: Biota vs. Habitat Assessment

Metric	Available Cover	Embeddedness	Pool Substrate	Velocity/ Depth Regime	Pool Variability
Fish Shannon Diversity	0.475	0.953	0.088	0.999	0.833
Fish Species Richness	-0.149	0.579	0.669	0.774	0.998
Fish Evenness	0.998	0.765	-0.796	0.568	-0.025
Macroinvertebrate Shannon Diversity	0.547	0.975	0.004	0.999	0.783
Macroinvertebrate Species Richness	0.004	0.697	0.546	0.862	0.995
Macroinvertebrate Species Evenness	0.601	-0.122	-0.942	-0.38	-0.582
Macroinvertebrate HBI	-0.601	-0.987	0.063	-0.994	-0.74

Metric	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles	Channel Sinuosity
Fish Shannon Diversity	-0.993	-0.997	-0.696	0.962	0.97
Fish Species Richness	-0.864	-0.843	-0.988	0.933	0.629
Fish Evenness	-0.431	-0.466	0.236	0.281	0.723
Macroinvertebrate Shannon Diversity	-0.98	-0.987	-0.634	0.936	0.987
Macroinvertebrate Species Richness	-0.931	-0.916	-0.952	0.977	0.741
Macroinvertebrate Species Evenness	0.521	0.487	0.943	-0.651	-0.184
Macroinvertebrate HBI	0.964	0.974	0.581	-0.91	-0.995

Metric	Bank Stability	Bank Vegetative Protection	Riparian Vegetative Zone Width
Fish Shannon Diversity	-0.813	-0.428	0.999
Fish Species Richness	-1	-0.885	0.774
Fish Evenness	0.059	0.537	0.567
Macroinvertebrate Shannon Diversity	-0.761	-0.35	0.999
Macroinvertebrate Species Richness	-0.991	-0.803	0.862
Macroinvertebrate Species Evenness	0.869	1	-0.38
Macroinvertebrate HBI	0.717	0.287	-0.994

Bayes' Factors: Biota vs. Land Use Categories

Metric	Open Water	Developed, Open	Developed, Low	Developed, Medium	Developed, High
Fish Shannon Diversity	-0.838	0.697	-1	-0.998	0.654
Fish Species Richness	-0.998	0.988	-0.818	-0.84	0.977
Fish Evenness	0.015	-0.236	-0.507	-0.472	-0.292
Macroinvertebrate Shannon Diversity	-0.789	0.634	-0.993	-0.988	0.588
Macroinvertebrate Species Richness	-0.996	0.952	-0.896	-0.913	0.933
Macroinvertebrate Species Evenness	0.846	-0.943	0.446	0.481	-0.961
Macroinvertebrate HBI	0.747	-0.581	0.984	0.976	-0.533

Metric	Barren Land	Deciduous Forest	Mixed Forest	Shrub/ Scrub	Herbaceous
Fish Shannon Diversity	-0.823	0.698	0.147	0.723	0.694
Fish Species Richness	-0.999	0.988	-0.477	0.993	0.987
Fish Evenness	0.043	-0.234	0.915	-0.2	-0.24
Macroinvertebrate Shannon Diversity	-0.772	0.635	0.229	0.662	0.631
Macroinvertebrate Species Richness	-0.993	0.953	-0.336	0.963	0.951
Macroinvertebrate Species Evenness	0.86	-0.942	0.837	-0.93	-0.944
Macroinvertebrate HBI	0.728	-0.582	-0.294	-0.61	-0.578

Metric	Hay/Pasture	Cultivated Crops	Woody Wetlands	Emergent Wetlands
Fish Shannon Diversity	-0.564	-0.743	-0.813	-0.697
Fish Species Richness	-0.947	-0.996	-1	-0.988
Fish Evenness	0.398	0.171	0.06	0.236
Macroinvertebrate Shannon Diversity	-0.493	-0.684	-0.761	-0.634
Macroinvertebrate Species Richness	-0.886	-0.97	-0.991	-0.952
Macroinvertebrate Species Evenness	0.986	0.919	0.869	0.943
Macroinvertebrate HBI	0.434	0.633	0.716	0.581

Bayes' Factors: Biota vs. Habitat Assessment

Metric	Available Cover	Embeddedness	Pool Substrate	Velocity/ Depth Regime	Pool Variability
Fish Shannon Diversity	0.475	0.953	0.088	0.999	0.833
Fish Species Richness	-0.149	0.579	0.669	0.774	0.998
Fish Evenness	0.998	0.765	-0.796	0.568	-0.025
Macroinvertebrate Shannon Diversity	0.547	0.975	0.004	0.999	0.783
Macroinvertebrate Species Richness	0.004	0.697	0.546	0.862	0.995
Macroinvertebrate Species Evenness	0.601	-0.122	-0.942	-0.38	-0.582
Macroinvertebrate HBI	-0.601	-0.987	0.063	-0.994	-0.74

Metric	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles	Channel Sinuosity
Fish Shannon Diversity	-0.993	-0.997	-0.696	0.962	0.97
Fish Species Richness	-0.864	-0.843	-0.988	0.933	0.629
Fish Evenness	-0.431	-0.466	0.236	0.281	0.723
Macroinvertebrate Shannon Diversity	-0.98	-0.987	-0.634	0.936	0.987
Macroinvertebrate Species Richness	-0.931	-0.916	-0.952	0.977	0.741
Macroinvertebrate Species Evenness	0.521	0.487	0.943	-0.651	-0.184
Macroinvertebrate HBI	0.964	0.974	0.581	-0.91	-0.995

Metric	Bank Stability	Bank Vegetative Protection	Riparian Vegetative Zone Width
Fish Shannon Diversity	-0.813	-0.428	0.999
Fish Species Richness	-1	-0.885	0.774
Fish Evenness	0.059	0.537	0.567
Macroinvertebrate Shannon Diversity	-0.761	-0.35	0.999
Macroinvertebrate Species Richness	-0.991	-0.803	0.862
Macroinvertebrate Species Evenness	0.869	1	-0.38
Macroinvertebrate HBI	0.717	0.287	-0.994