

Impacts of Land Use and Sedimentation on Brown Trout (*Salmo trutta*) Populations in a High Quality (Class A) Fishery

By: Eden Brody
April, 2024



Allegheny College
Department of Biology

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A Senior Comprehensive Project in Partial Fulfillment of the Requirements
for a Bachelor of Science Degree from Allegheny College

*I hereby recognize and pledge to fulfill my responsibilities as defined in the Honor Code
and to maintain the integrity of both myself and the College community as a whole.*

Pledge

Approval by the Senior Thesis Committee:

Dr. Casey Bradshaw-Wilson

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Abstract

In recent decades, anthropogenic land alteration has intensified worldwide, with land alteration increasing erosion processes, causing increased waterbody sedimentation. Increased fine sediment deposition has been linked to declines in the abundance of many Salmonid fishes (trout and salmon). However, the mechanisms linking increased sediment to declines in salmonid abundance are idiosyncratic and dependent upon the species, stream habitat, and watershed landscape. Caldwell Creek is a Class A Brown Trout (*Salmo trutta*) fishery in Northwest Pennsylvania that is reported to have a decline in trout abundance. This decline is hypothesized to be associated with increased fine sediment inputs within the watershed. To evaluate the extent and potential causes of this decline in trout abundance, data on physical habitat, water quality, sedimentation levels, macroinvertebrate communities, and trout populations were collected from 10 sample sites in the Caldwell and Pine Creek watersheds. Analysis was conducted to determine the differences in historic and current trout population metrics and the connections between abiotic stream inputs and trout populations. Results indicated a significant decline in the intactness of the macroinvertebrate communities ($p = 0.0151$) and the abundance of Brown Trout ($p = 0.0407$) in the West Branch of Caldwell Lower site, as well as a significant decline in the biomass of brown trout ($p = 0.0496$) in the West Branch of Caldwell Upper site. A principal component analysis on abiotic inputs revealed that water temperature, stream-sediment loads, habitat quality, and watershed area were the primary factors influencing trout abundance in Caldwell Creek. This indicates that changes in thermal regimes due to climatic trends and increases in sediment loads from land use changes are likely responsible for the decline in trout abundance. The Caldwell Creek watershed should be a prioritization for both restoration and mitigation to restore the sustainability of the Caldwell Creek Brown Trout Fishery.

Introduction

In recent decades, the conversion of natural areas for human purposes has increased, which has negatively impacted both terrestrial and aquatic ecosystems (Tilman 1999, Whitney and Decant 2003, Allan 2004, Foley et al. 2005). The conversion of natural land cover stresses aquatic ecosystems, as landscape changes cause increases in pollutants to waterways. Pollutants include sewage effluents, nutrients, and the focus of this study, fine sediments (Burns 1972, Megahan and Kidd 1972, Scanlon et al., 2007, Allan 2004, Walling and Fang 2003). Sediment enters waterways through erosion of terrestrial surfaces, and several factors can influence the severity of sedimentation. Those factors can include the type of anthropogenic land use, the topography of the watershed, local rainfall patterns, hydrologic conditions of the stream, and characteristics of the stream channel (Garde and Raju 2000).

In altered landscapes, natural barriers to the movement of water, such as ponds and vegetation, are reduced, decreasing the amount of time water can infiltrate soil. Furthermore, water cannot infiltrate into impervious surfaces or compacted soils, both of which are prevalent around human infrastructure (Brun and Band 2000, Gregory et al. 2006). Reduced groundwater infiltration leads to greater runoff, increasing peak discharge rates of streams and allowing for the increased erosion of streambanks and floodplains (Chithra et al. 2015, Hornung and Newson 1986, Seutloali and Beckedahl 2015). As such, altered watersheds have increased levels of fine sediment (Walling and Fang 2003).

Increased levels of fine sediments have been well-documented as causing declines in aquatic biodiversity, macroinvertebrate density, and overall stream health (Angradi 1999, Waters 1995), which can be manifested through multiple mechanisms. Fine sediments have been shown to reduce fish feeding, growth, and reproductive success (Redding et al. 1987, Sutherland and

Meyer 2007, Henley et al. 2000, Kemp et al. 2011). Studies have shown that populations of Salmonid fishes, which include salmon and trout, are particularly susceptible to elevated levels of fine sediments (Ramezani et al. 2014, Suttle et al. 2004, Shaw and Richardson 2001). This is especially concerning due to the commercial, recreational, and ecological value of Salmonid fisheries (Dorison 2012, Layman et al. 1996, Clark et al. 2006). Sediment negatively impacts Salmonid populations by reducing salmonid prey density, reducing feeding efficiency, increased environmental stress, impaired water quality, and diminished reproductive success (Ramezani 2014, Shaw and Richardson 2001, Redding et al. 1987, Matthews and Berg 1997, Fisher 1963, Bianchi 1963).

Increased sediment deposition has been associated with changes to macroinvertebrate communities, which many salmonids rely on for their diet (Angradi 1999, Ramezani 2014, Shaw and Richardson 2001). Interstitial spaces within the streambed are vital habitats for many benthic macroinvertebrates (Gayraud and Philippe 2003). Increased sediment deposition therefore leads to a reduction in macroinvertebrate habitat, reductions in biodiversity, and an increase in fine sediment-adapted species as a result of habitat homogenization (Reid et al. 2010, Lenat et al. 1981, Gayraud and Philippe 2003). This environmental change can select against certain macroinvertebrate traits, such as large-size bodies, non-cylindrical body designs, and rigid exoskeletons (Gayraud and Philippe 2001, Angradi 1999). Since larger macroinvertebrates are more energy-dense, a reduction in the abundance of large macroinvertebrates could reduce salmonid feeding efficiency (De Crespín De Billy and Usseglio-Polatera 2002).

Increased sediment inputs can also alter the pH, salinity, and temperature of streams (Baeseman et al. 2006, Cañedo-Argüelles et al. 2013). Increased landscape erosion leads to more salts and pH-altering compounds entering streams; Salmonid growth and survival are reduced in

low pH or high salinity environments (Gunn 1986, McKay and Gjerde 1985). Sediment can also decrease the velocity and depth of the channel, which can subsequently increase the average temperature of streams as the water has more time to absorb heat from both the sun and the surrounding atmosphere (Studinski et al. 2012). The subsequent increase in temperature causes a decrease in the dissolved oxygen content of the water (Reis Oliveira et al. 2019, Rosgen 1994). At temperatures above 18.7-19.5°C or dissolved oxygen concentrations below 9 mg/L, salmonids exhibit impaired growth, digestion, and metabolic processes, causing increased physiological stress and reduced survival rates (Elliott and Hurley 2001, Fisher 1963). Gradual changes in the dissolved oxygen concentration and thermal regimes of watersheds can indeed cause the decline of salmonid populations (Matthews and Berg 1997)

Sediment also affects the flow regime of streams, which changes in-stream habitat characteristics such as depth, water velocity, habitat homogeneity, streambed permeability, and spawning areas (Rosgen 1994, Reid et al. 2010, Bolliet and Bardonnnet 2017, Soulsby et al. 2001). Salmonids require a variety of habitats throughout their life cycle, and because sedimentation homogenizes the streambed, it causes a reduction in habitat diversity (Richer et al. 2019). Additionally, to complete their life cycle, Salmonids deposit eggs into gravel substrates in the streambed. When this spawning substrate is embedded with fine sediments, it decreases fry survival (Bianchi 1963). This decline in egg hatch rates can be attributed to the sediment decreasing the permeability of spawning gravel, which causes the water around the eggs to stagnate and slowly lose its dissolved oxygen. With a low hatch rate due to poor oxygen saturation and fry getting trapped within spawning gravels, sediment can reduce natural recruitment for Salmonid populations (Bolliet and Bardonnnet 2017, Soulsby et al. 2001).

Despite the link between sediment and salmonid declines being well understood, mitigating the effects of sediment is difficult as it is a nonpoint source pollutant. Increases in sediment come from changes in land cover, which could be caused by increased development, construction, or deforestation at either a local (riparian-scale) or regional scale (watershed-scale) (Binkley and Brown 1993). Determining the areas contributing to high sediment inputs is essential in mitigating the effects of sedimentation, and sediment impacts can be mitigated with erosion control measures. Such control measures include restorations like riparian plantings and streambank stabilizations (Zaimes et al 2006, Shields et al 1995). However, diffuse activities like agriculture make it particularly difficult to identify the sources of major sedimentation (Duncan 2014, Ricci et al. 2020). This means that the impacts of sediment and following mitigating efforts are highly idiosyncratic and watershed-specific.

Brown Trout (*Salmo trutta*) are originally native to Eurasia, however, they have been widely introduced outside their native range. This was to establish brown trout fisheries in waters that otherwise did not support game-fish species (McIntosh et al. 2012). Pennsylvania received its first brown trout from Germany in 1886 (Hilburn 2018). These first fish were used to replenish Pennsylvania's waterways, which had become depleted of its native Brook Trout (*Salvelinus fontinalis*) because of habitat degradation (Detar 2007). Brown trout are now found throughout Pennsylvania, with the Pennsylvania Fish and Boat Commission stocking 686,000 Brown Trout into Pennsylvania waterways in 2022 (Pennsylvania Fish and Boat Commission 2022). Brown trout have established wild populations throughout Pennsylvania, with many of the watersheds they inhabit being valued as high-quality sport fisheries (Pennsylvania Fish and Boat Commission 2023). The recreational fisheries these exotic populations of brown trout facilitate have made them of high conservation value to fisheries managers.

This study will look at the Pine and Caldwell Creek Watersheds, which are tributaries to Oil Creek, which is a tributary to the Upper Allegheny River. Both Pine and Caldwell Creek primarily drain forested areas with low population densities (76-87% forested land cover, 2-6% developed land cover). These watersheds are known for harboring healthy populations of Brown Trout, with the West Branch of Caldwell Creek being classified as "Class A Wild Brown Trout Waters" by the Pennsylvania Fish and Boat Commission (Pennsylvania Fish and Boat Commission 2023). This classification is reserved for Pennsylvania streams that support a large biomass of naturally reproducing trout (>40 kg/ha) and are independent of stocked trout populations. However, there have been anecdotal reports of increased sediment and decreased brown trout abundance in Caldwell Creek

The purpose of this study was to investigate the spatial and temporal patterns of brown trout abundance within a high-quality (Class A) trout fishery, which was composed of three objectives. The first objective was to evaluate what locations within the watershed experienced long-term population declines in brown trout abundance and long-term declines in the quality of macroinvertebrate communities. The second objective was to perform a spatial comparison across all sampling locations using a suite of abiotic variables to determine what environmental characteristics explained brown trout abundance and macroinvertebrate communities across the watershed. Based on the rationale described above, we hypothesized that locations with higher temperatures and higher levels of sediment would have lower abundances of brown trout and more tolerant macroinvertebrate communities. The third objective was to utilize GIS analyses to determine whether any potential land use changes have occurred over time which could explain population declines. We hypothesize that locations experiencing greater land use changes will

experience greater brown trout population declines and greater declines in macroinvertebrate quality.

Methods

Site	Latitude	Longitude	Watershed Area (km ²)	Stream Order
Caldwell Creek Mid-Upper	41.680188	-79.582081	96	4
Caldwell Creek Mid-Lower	41.672195	-79.593554	104	4
Caldwell Creek Upper	41.685143	-79.576193	87	4
Caldwell Creek Lower	41.668569	-79.597697	107	4
West Branch Caldwell Lower	41.723113	-79.561467	50	3
West Branch Caldwell Upper	41.721126	-79.580084	33	3
Middle Branch Caldwell	41.73124	-79.565042	9	2
East Branch Caldwell	41.710291	-79.545169	29	3
Stony Hollow	41.676456	-79.592676	7	2
Pine Creek	41.629027	-79.590379	75	4

Table 1: Coordinates, watershed size, and stream order for the ten sample sites.

Study Region

Data was collected from ten study sites with varying land-use intensities in the Caldwell and Pine Creek Watersheds (Figure 1) (Table 1). The watersheds of both Caldwell and Pine Creek are largely forested (76-87% forest land cover) and harbor several logging and gas drilling operations. Of the sites sampled, West Branch Caldwell Lower and West Branch Caldwell Upper are classified as “Class A Wild Trout Waters” (Pennsylvania Fish and Boat Commission 2023).

GIS Analysis

The watersheds of each sample site were delineated in ArcGIS (Release 10) using georeferenced USGS topographic maps (ESRI. 2011, ArcGIS Desktop: Release 10) (U.S. Geological Survey 2022) following the methods of Kirk et al. (2017, 2018). For each of the

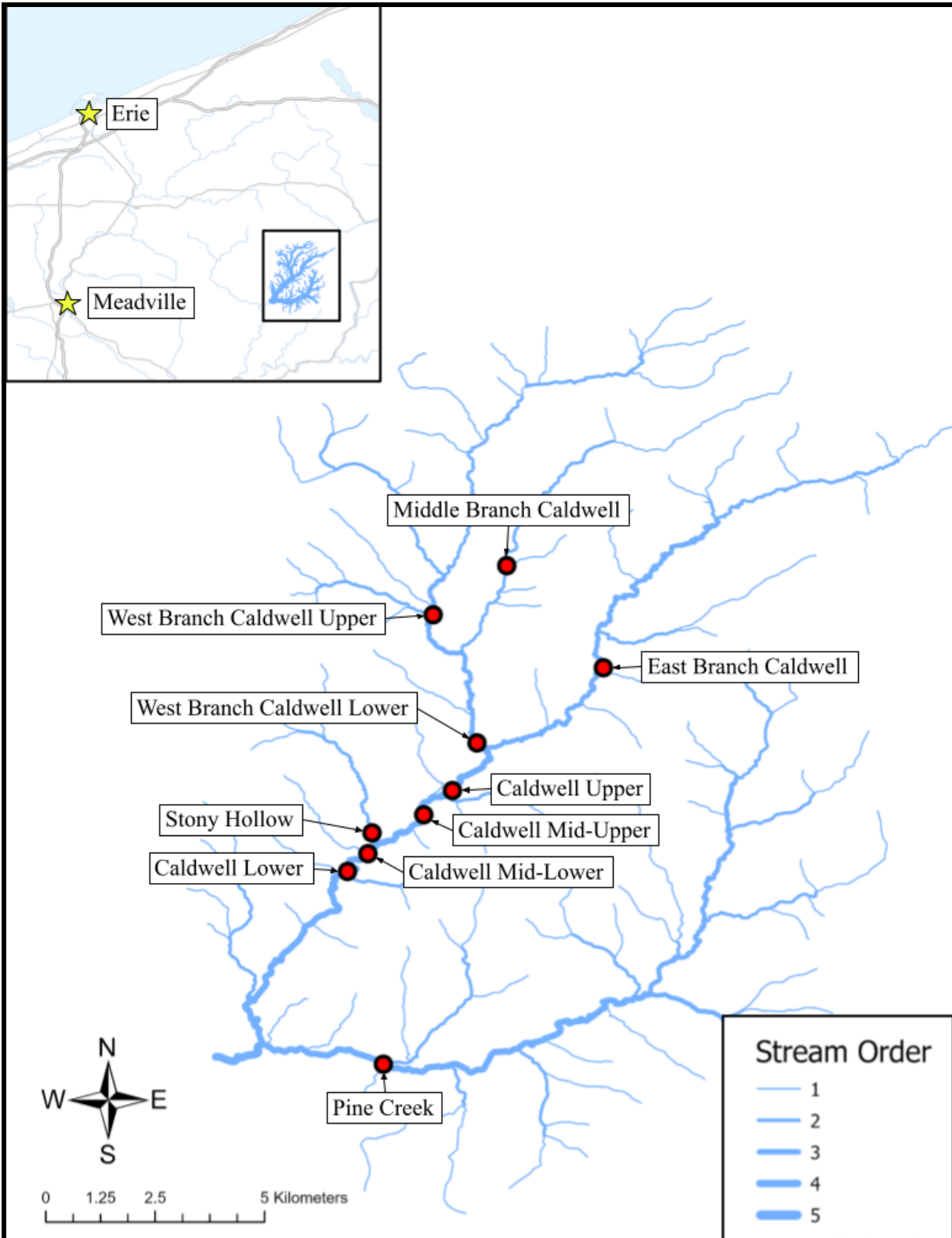


Figure 1: Map of the study region with Strahler Stream Order and sampling locations (U.S. Geological Survey 2023B).

sample sites, upstream watershed land use was calculated for the years 2001 and 2021 using the NLCD2001 and 2021 Land Cover datasets (U.S. Geological Survey 2003, Dewitz 2023). NLCD land cover categories were consolidated into wetland land cover, developed land cover, agricultural land cover, and forested land cover (Table 2).

Benthic Macroinvertebrate Surveys

Macroinvertebrate community composition was quantified following the Pennsylvania Freestone Macroinvertebrate Collection Method (Bureau of Clean Water 2015). This is a standardized collection method

for sampling macroinvertebrate communities in Pennsylvania streams. Samples were collected during the Spring-Winter transition (February-April), Summer (May-September), and Fall-Winter transition (October-December) to control for seasonality. For each sample, invertebrates were collected with a D-frame net from 6 kick samples in 2-3 distinct riffle habitats by disturbing the substrate for 60 seconds in 2-3 randomly selected locations within each riffle habitat. The samples were then aggregated and preserved in 70% ethanol until processing.

Each macroinvertebrate sample was then processed to calculate the Pennsylvania Freestone Index of Biological Integrity (IBI) (Bureau of Clean Water 2015). This index incorporates six different biological metrics to determine the health of macroinvertebrate

NLCD Land Cover Category	Land Cover
Deciduous Forest Evergreen Forest Mixed Forest	Forest
Barren Land Developed, Open Space Developed, Low-Intensity Developed, Medium Intensity Developed, High-Intensity	Developed
Open Water Woody Wetlands Emergent Herbaceous Wetlands	Wetland
Shrub/Scrub Grassland/Herbaceous Pasture/Hay Cultivated Crops	Agricultural

Table 2. Consolidated NLCD land cover categories.

communities, scoring communities from 0-100 with 100 indicating an intact macroinvertebrate community. A subsample of 200 to 240 macroinvertebrates was selected from each macroinvertebrate sample for identification, with a minimum of 160 invertebrates needed for calculating the IBI. Invertebrates were identified to the genus level under a microscope using published identification guides (Peckarsky et al. 1990, Merritt and Cummins, 2019).

Macroinvertebrate genera were then assigned a pollution tolerance value (PTV), following Bureau of Clean Water specifications. This PTV ranges in value from 0-10 and represents macroinvertebrate sensitivity to organic pollutants and sedimentation, with 0 indicating very sensitive and 10 indicating very tolerant macroinvertebrates. From this information, total taxa richness, EPT taxa richness, Beck's Index, Hilsenhoff Biotic Index, Hilsenhoff Biotic Index, and percent sensitive individuals were calculated (Appendix 1). These metrics were then standardized on a scale from 1-100 and averaged to calculate the IBI (Appendix 1) (Bureau of Clean Water 2015).

Water Chemistry

Temperature (°C), dissolved oxygen (mg/L), conductivity (ppm), and pH were recorded during each macroinvertebrate and fish survey. Conductivity (a measure of salinity) was measured using a Hanna Instruments Combo Testing Meter. Dissolved oxygen and temperature were measured using a YSI ProSolo Digital Water Quality Meter, and pH was measured using an HM Digital PH-200 Handheld pH Meter.

Water temperature (°C) was continuously monitored from East Branch Caldwell, West Branch Lower, Caldwell Lower, Caldwell Upper, and Stoney Hollow Run from May to September 2023 using HOBO Water Temp Pro v2 Loggers. Summer average temperature (°C)

and July Average Temperature (°C) was calculated. Sites without temperature loggers had their temperature metrics estimated using nearby sites and field measurements as reference.

Habitat Assessments

Habitat assessments were conducted for each sample site using the Pennsylvania Department of Environmental Protection's Water Quality Network Habitat Assessment (WQN), and an adjusted version of a Riparian, Channel, and Environmental Inventory (RCE). These assessments were conducted by the same surveyor between sites to limit subjectivity. The WQN is a standardized habitat assessment protocol developed by the Pennsylvania Department of Environmental Protection. It uses 12 different parameters to quantify substrate embeddedness, flow regimes, disruptive pressures, and in-stream habitat diversity (Bureau of Clean Water 2021) (Appendix 2). The RCE was originally designed for European streams (Petersen 1992), however, for our purposes, a version modified for Western Pennsylvania was used (Norris 1997). This assessment protocol uses 12 different metrics to quantify riparian intactness, flow regimes, substrate embeddedness, and terrestrial inputs (Appendix 3).

Sediment Data

Sedimentation was quantified for streams using several metrics. First, suspended sediment samples were collected during base-flow and high-flow events. High-flow events were defined as floods with significant sediment-moving capabilities following high precipitation events. During these events, a 100 mL water sample was collected, which was used to quantify total suspended sediment (TSS). Second, sediment embeddedness was calculated using a bulk sediment sampler following established sampling methods (Buendia et al. 2013, Murphy et al. 2015). The sediment sampler (29.5cm diameter) was pushed into the substrate to isolate the contents inside the sediment sampler, and the substrate was agitated for 60 seconds to suspend

any deposited sediments into the water. A sampling jar was then filled and the water height was measured to determine what fraction of the collected sample was of the total bulk sampler's volume. All sediment samples were refrigerated below 5°C until processing.

In the laboratory, sediment samples were processed to calculate the turbidity and sediment content of the sample. To calculate turbidity, the sample was agitated to suspend any sediments that settled out of the solution, TSS was then measured using a LaMotte Turbidity Tester. To determine sediment content, a 50ml sub-sample of the sediment sample was filtered using a vacuum filtration system and then dried at 55°C for 48 hours. After drying, the filter was weighed and deposited sediments (g/m^2) was calculated.

Fish Collection

Each sample site was surveyed to determine trout abundance between June and October 2023 using established electrofishing methods (Kirk et al. 2017, 2018). Sampling was conducted with a pulsed-DC backpack electrofisher (Smith-Root Model 12; 15–120 Hz; 200–1000 V) during base flow conditions. Electrofishing was conducted over a 150-500 meter reach using three-pass depletion to ensure high capture rates for trout. These reaches contained a variety of riffle, run, and pool habitats, as well as the riffles sampled for macroinvertebrates. Electrofishing began at the downstream extent of the sampling area moving upstream in a zig-zag pattern from bank to bank, herding fish upstream towards natural barriers.

After electrofishing was completed, fish species were recorded, and non-salmonid species were released, while trout were processed for additional data. Hectares surveyed were calculated in ArcGIS.

Trout Population Metrics

Brown trout collected during sampling were measured to the nearest millimeter using total length measurement for assignment of age classes based on length-frequency histograms (Kirk et al. 2017, 2018). The weight (kg) of each trout was then estimated using a length-weight model based on a power function ($y = (1.88E-8) x^{2.9}$) using data from a subset of brown trout that had measured weights ($n = 46$). Overall trout abundance, young of year (trout less than 100 mm in length) abundance, and total trout biomass were recorded. Data was then standardized per hectares surveyed.

Site	Historic Fish Surveys	Historic Macroinvertebrate Surveys	Survey Years
West Branch Caldwell Lower	6	21	1968-2019
West Branch Caldwell Upper	5	0	1968-2009
Caldwell Mid-Upper	0	0	NA
Caldwell Mid-Lower	0	0	NA
Caldwell Upper	1	1	2007-2010
Caldwell Lower	1	1	2000-2010
East Branch Caldwell	1	2	2007-2009
Middle Branch Caldwell	1	1	2006-2009
Pine Creek	1	1	1993-2008
Stony Hollow	1	1	2007-2019

Table 3: Number of historic samplings included in this study.

Historic Data

Historic fish and macroinvertebrate data was provided by surveys completed by the Pennsylvania Fish and Boat Commission (PFBC), prior Allegheny College researchers, and the Pennsylvania Department of Environmental Protection (Kirk 2023, Department of Environmental Protection Macroinvertebrate Taxa Dataset). The majority of this data was on the

“Class A” section of the West Branch of Caldwell (West Branch Upper and West Branch Lower sites), however, each subbasin had at least one historic fish and macroinvertebrate survey (Table 3).

Data Analysis

Data analysis was conducted in JMP (JMP Pro 17) and PAST (PAST Version 4.16). For this analysis, a p-value <0.05 is considered to be statistically significant while a p-value <0.10 is considered to be marginally significant.

For Objective 1, sample sites with at least three historic electrofishing or macroinvertebrate surveys were used to determine biotic trends over time. Trout population metrics (abundance, YOY abundance, biomass) and macroinvertebrate IBI scores were tested over time using linear regressions. Sample sites without enough historical data for statistical analysis had biotic changes reported in percent deviation from historical averages.

A principal component analysis (PCA) was utilized for objective 2, to determine the abiotic variables that govern trout populations in Caldwell Creek. Water quality variables (water temperature, pH, dissolved oxygen, conductivity, summer water temperature, and July water temperature), habitat quality variables (Appendices 2, 3), sediment variables (substrate embeddedness, low flow TSS, and high flow TSS), and land cover variables (watershed area, forested land cover, agricultural land cover, wetland land cover, and developed land cover) were added to a PCA model and allowed to sort among orthogonal axes using iterative imputation to estimate any missing values. Principal components that accounted for more than 10% of variance were then examined, defining significant variables as those with loading values > 0.6 . These principal components were then tested against contemporary trout and macroinvertebrate metrics using linear regressions.

To determine land use changes over time for Objective 3, we compared changes in each of the land cover categories (forested land cover, agricultural land cover, wetland land cover, and developed land cover) between 2001 and 2021 for each sample site. This was then compared to changes in trout abundance and YOY trout abundance for said sites using linear regressions to determine potential connections between land cover change and changes in trout abundance.

Results

Objective I:

Temporal changes in macroinvertebrate IBI scores varied between the sample sites. IBI scores for Stony Hollow, the Main Stem of Caldwell, the West Branch of Caldwell Lower, and the Middle Branch of Caldwell decreased compared to historical averages, while IBI scores increased for Pine Creek and the East Branch of Caldwell (Appendix 4). The West Branch of Caldwell Lower was the only site with enough historic macroinvertebrate samples for statistical analysis, with a statistically significant decline in IBI scores over time ($p = 0.0151$) (Figure 2).

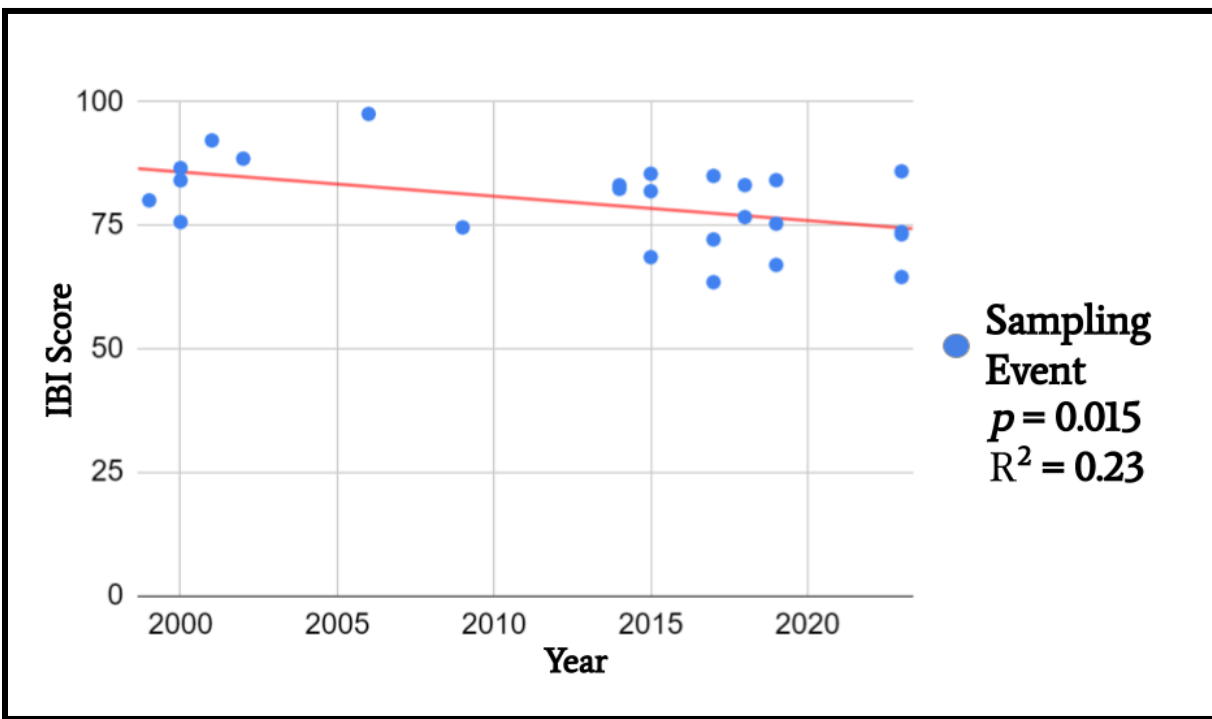


Figure 2: Graph of macroinvertebrate IBI over time for the West Branch Lower.

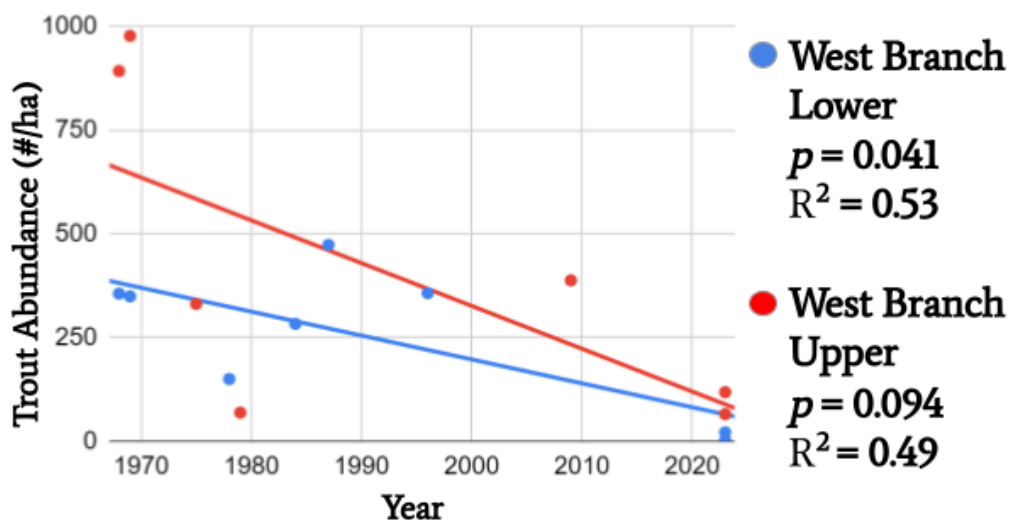
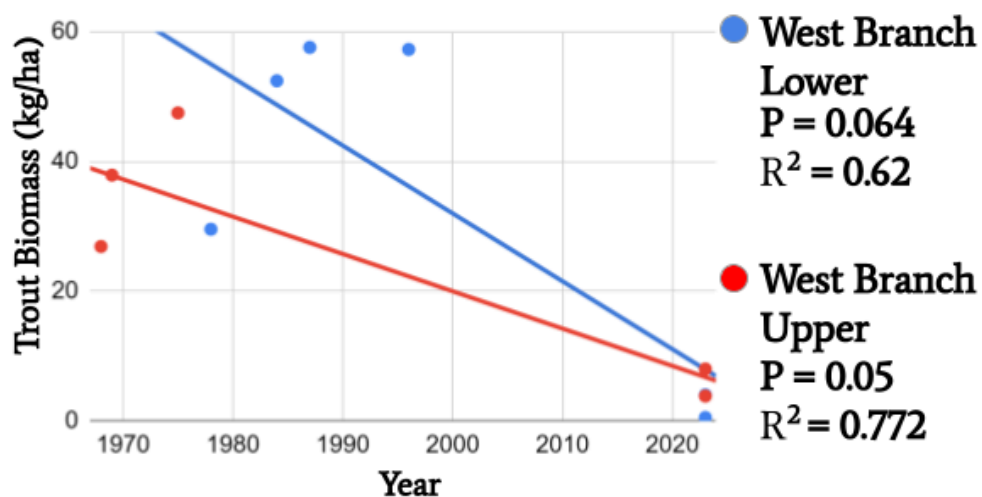
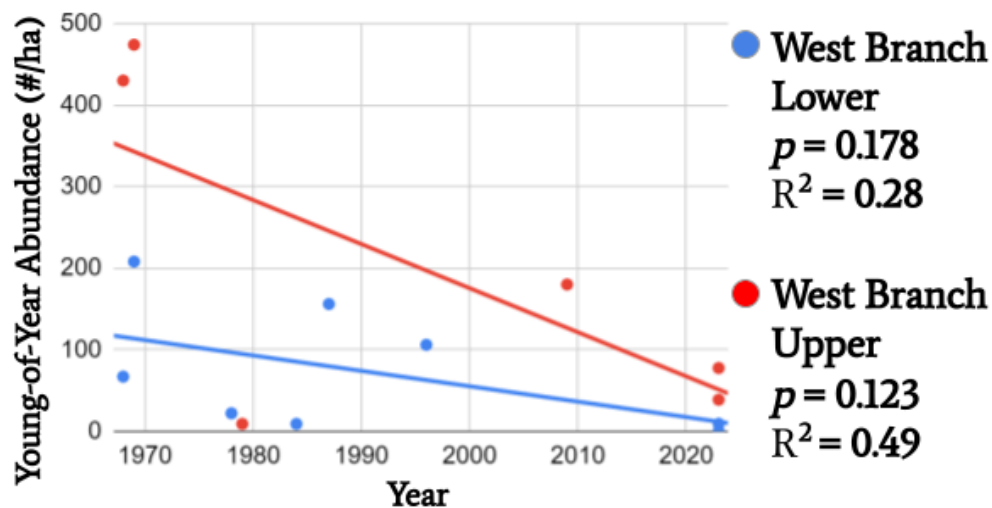


Figure 3: Graphs of trout abundance (#/ha), YOY trout abundance (#/ha), and trout biomass (kg/ha) for the West Branch Caldwell sites.



All sample sites experienced a decline in trout abundance, YOY trout abundance, and trout biomass compared to historical averages, with none of the sample sites currently achieving brown trout productivity above the Class A Wild Trout threshold (>40 kg/ha) (Appendix 5). Of these sites, the Main Stem of Caldwell, Pine Creek, the East Branch of Caldwell, and the West Branch of Caldwell Lower experienced large-scale declines in both overall trout abundance ($>75\%$ reduction), and YOY trout abundance ($>90\%$ reduction). The only sites that didn't experience as severe a decline in brown trout abundance and YOY trout abundance were the West Branch of Caldwell Upper (71% and 68% reduction respectively), and the Middle Branch of Caldwell (46% and 36% reduction respectively).

The two West Branch of Caldwell sample sites were the only two with enough historic electrofishing surveys for statistical analysis. The lower site on the West Branch of Caldwell Creek experienced a statistically significant decline in trout abundance ($p = 0.0407$), a non-significant decline in YOY trout abundance ($p = 0.1776$), and a marginally significant decline in trout biomass ($p = 0.0639$) (Figure 3). The upper site on the West Branch of Caldwell Creek experienced a marginally significant decline in trout abundance ($p = 0.0944$), a non-significant decline in YOY trout abundance ($p = 0.1228$), and a statistically significant decline in trout biomass ($p = 0.0496$) (Figure 3).

Objective II:

The first two principal component (PC) axes were determined to be significant predictors of site variance with the components accounting for 49.5% and 14.88% of variance respectively (Table 4). Variables that significantly loaded on PC1 were July temperature (-0.69), summer temperature (-0.67), watershed area (-0.66), high-flow TSS (-0.64), and most habitat quality parameters (21/24 parameters were significant and all loaded between 0.7 and 1) (Appendix 6).

Variables that loaded significantly on PC2 were agricultural land cover (-0.77), wetland land cover (0.66), developed land cover (0.68), watershed area (0.7), RCE land-use pattern beyond immediate riparian zone (0.79), and RCE vegetation of riparian zone within 10 m of channel (-0.79) (Appendix 6).

Principal Component	Eigenvalue	Variance (%)
1	18.3165	49.504
2	5.50624	14.882
3	2.86038	7.7307
4	2.64827	7.1575
5	2.04994	5.5404
6	1.47828	3.9954
7	1.09772	2.9668
8	0.900442	2.4336
9	0.715345	1.9334
10	0.49649	1.3419

Table 4: Principal components with their associated eigenvalues and variance accounted for in the model.

Now looking at these components in terms of predictors of trout abundance and macroinvertebrate community intactness, we found that PC1 was a statistically significant predictor of trout abundance ($\beta = 11.79$, $R^2 = 0.36$, $p = 0.0004$), YOY trout abundance ($\beta = 8.69$, $R^2 = 0.37$, $p = 0.0003$), and trout biomass ($\beta = 0.56$, $R^2 = 0.33$, $p = 0.0007$), while not being an accurate predictor of macroinvertebrate IBI score ($\beta = 0.67$, $R^2 = 0.09$, $p = 0.1306$) (Appendix 7). PC2 was determined to be a statistically significant predictor of trout abundance ($\beta = -45.89$, $R^2 = 0.18$, $p = 0.0166$), trout biomass ($\beta = -3.25$, $R^2 = 0.2$, $p = 0.0117$), and macroinvertebrate IBI

score ($\beta = -2.61$, $R^2 = 0.32$, $p = 0.0019$), and a marginally significant predictor of YOY abundance ($\beta = -28.74$, $R^2 = 0.11$, $p = 0.0629$) (Appendix 7).

Site	Change in Forest Cover (%)	Change in Wetland Cover (%)	Change in Developed Cover (%)	Change in Agricultural Cover (%)
Caldwell Mid-Upper	0.6	0.0	0.2	-0.8
Caldwell Mid-Lower	0.4	0.0	0.2	-0.6
Caldwell Upper	0.7	0.0	0.2	-0.9
Caldwell Lower	0.3	0.0	0.2	-0.5
West Branch Caldwell Lower	0.5	0.0	0.2	-0.7
West Branch Caldwell Upper	0.3	0.0	-4.4	-0.5
Middle Branch Caldwell	-0.5	-0.2	0.3	0.5
East Branch Caldwell	4.4	1.0	-4.4	-1.0
Stony Hollow	-2.9	0.0	0.3	2.6
Pine Creek	-0.5	0.0	0.2	0.2

Table 5: Change in NLCD land cover categories from 2001 to 2021.

Objective III:

Looking at changes to watershed land cover from 2001 to 2021, we determined that the East Branch of Caldwell was the only sample site to experience large-scale (>1%) land cover change. This took the form of increased forest land cover (4.4%) and wetland land cover (1%), as well as decreased developed land cover (-4.4%) and agricultural land cover (-1%) (Table 5). Testing changes in land cover categories as predictors of changes in trout abundance, YOY trout abundance, trout biomass, and macroinvertebrate IBI, we found that changes in land cover did not accurately reflect changes in any of these biotic metrics ($p > 0.1$). This leads to two possible

conclusions, the recent decline in brown trout abundance in the region is unrelated to increased land cover disturbance, or the NLCD land cover dataset is not accurately reflecting recent land cover changes.

Discussion

This study found that there is a high degree of spatial and temporal variation in trout populations within Caldwell Creek, with none of the sample sites currently achieving sufficient biomass for classification as a Class A Wild Trout Fishery (> 40 kg/ha) (Appendix 5). The Main Stem of Caldwell Creek and the East Branch of Caldwell Creek harbored no YOY trout, indicating a lack of natural reproduction. The West Branch of Caldwell Creek lower site, Stony Hollow, and Pine Creek had a low abundance of YOY trout (< 10 individuals/ha), indicating that although there is low population density, there is still natural reproduction. The West Branch of Caldwell Creek upper site and the Middle Branch of Caldwell Creek were the only sites with high YOY trout abundance (> 50 individuals/ha), indicating that these are the likely source populations for trout found at nearby sites such as the Main Stem of Caldwell and the West Branch of Caldwell lower site.

These findings contrast historic assessments of the sample sites, but are in line with the anecdotal reports that prompted this study. The Main Stem of Caldwell and the East Branch of Caldwell never harbored large populations of brown trout, and Stony Hollow has only been sampled since 2019. However, Pine Creek and the West Branch of Caldwell lower site experienced large-scale declines ($>95\%$) in trout abundance, YOY trout abundance, and trout biomass compared to historic surveys (Appendix 5). Additionally, the two sites that harbored the largest populations of trout, the Middle Branch of Caldwell Creek and the West Branch of

Caldwell Creek upper site also experienced declines in all these metrics with a 46% and 71% reduction in trout abundance respectively.

Looking at how PC1 correlated trout community metrics, trout were more abundant in sites with cold temperatures, small watershed areas, low sediment loads, and high habitat quality. This echoes previous studies, which have shown that trout exhibit increased physiologic stress with increasing temperature, decreased reproductive success with increased stream sediment loads, and decreased abundance within poor quality habitat (Elliott and Hurley 2001, Bianchi 1963, Thorn 1988). Additionally, trout exhibit differential life histories with stream size. Small streams contain the majority of spawning habitat necessary for reproductive success but are oligotrophic leading to decreased trout size and growth (Al-Chokhachy et al. 2022). Large streams provide more potential forage for trout but have decreased groundwater inputs leading to increased summer water temperatures, necessitating migration to thermally suitable environments (Elliot 2000). This leads to trout being more abundant in smaller streams, with stable water temperatures.

PC2 significantly correlated with trout community metrics, with trout being more abundant in smaller streams with less developed and wetland land cover, better RCE land use scores, and more agricultural land cover. While it is expected that trout would be more abundant in smaller, less developed streams, there were unexpected effects regarding wetland and agricultural land cover (Kemp and Spotila 1997). We posit this is an effect of local land use patterns within Caldwell Creek. Within the Caldwell Creek watershed, agricultural activities are largely present along the headwaters of the watershed, due to these sites' ability to provide the relatively flat topography necessary for agricultural activities (Figure 4). This leads to smaller streams having a higher proportion of agricultural land cover.

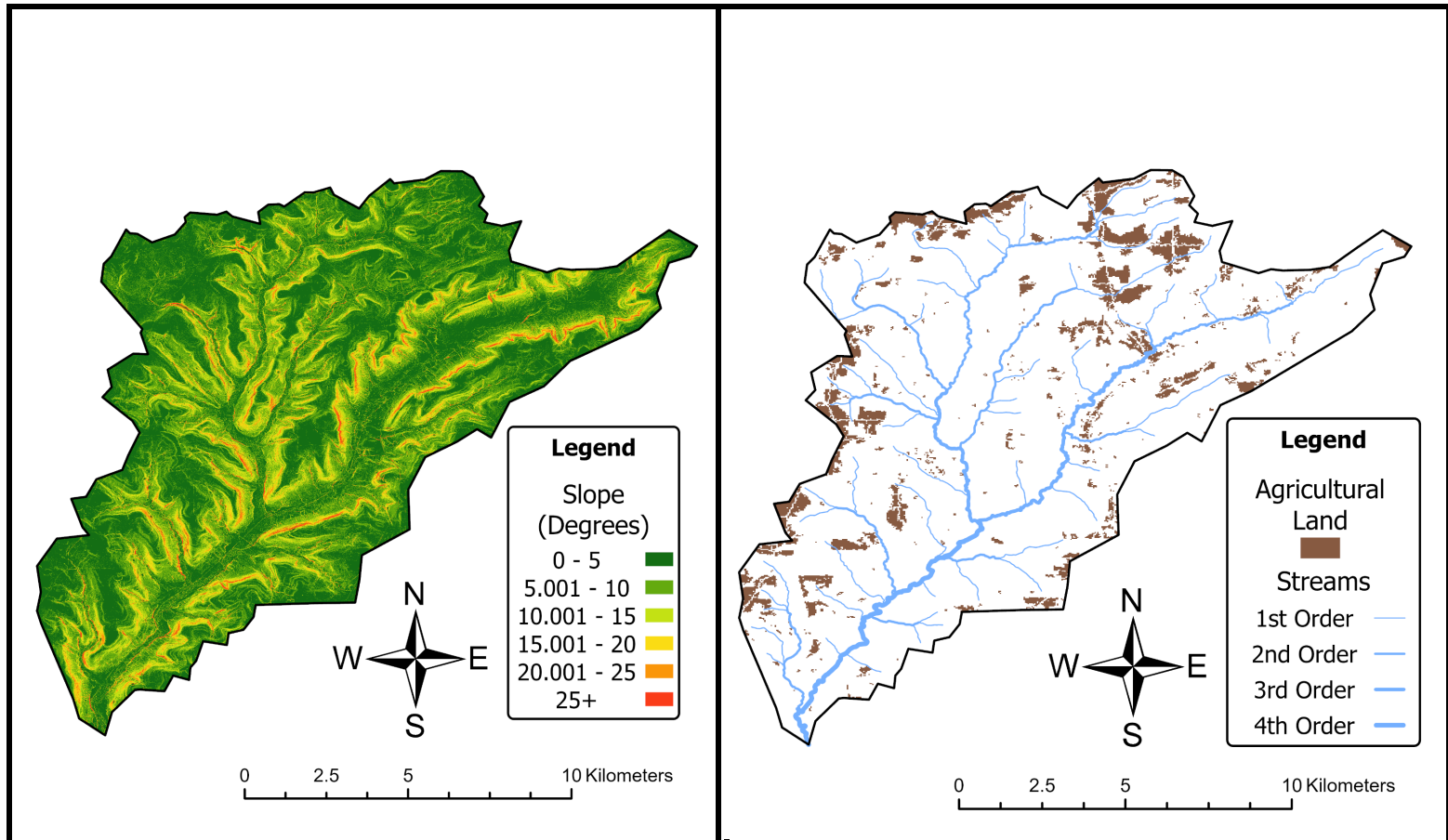
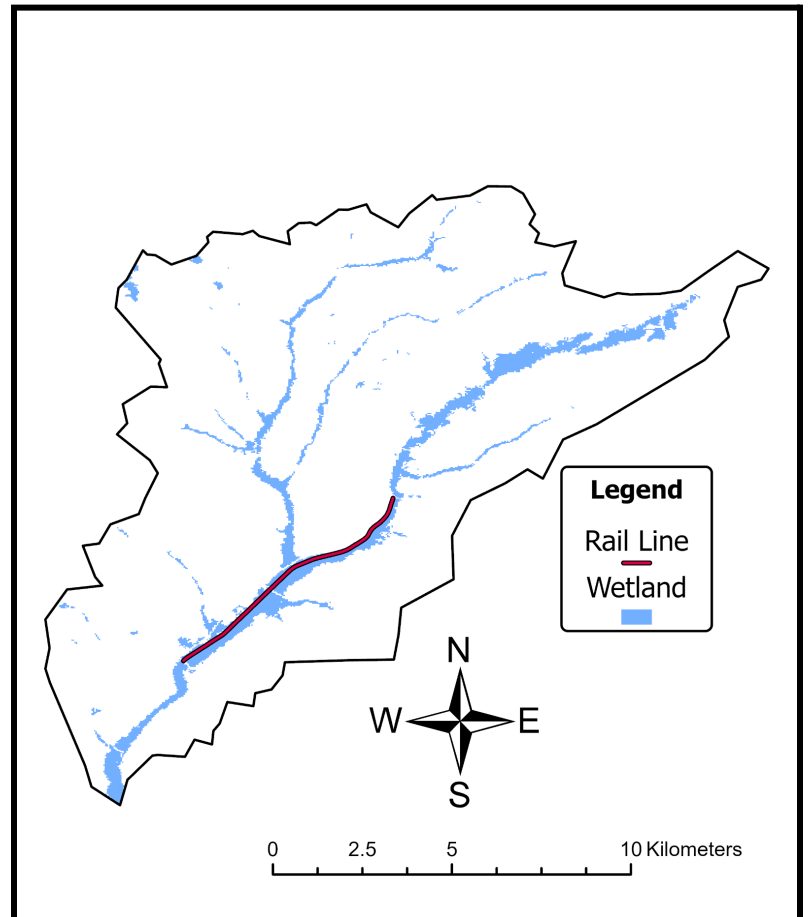


Figure 4: A slope map, and an agricultural land cover map overlaid with streams and their subsequent stream order for the Caldwell Creek Watershed (U.S. Geological Survey 2023A, 2023B, Dewitz 2023)

While agricultural activities are associated with increased erosion and stream sediment loads, as well as increased pollutants such as fertilizers and herbicides, the effects of these activities would impact sites differently. Once entering a stream, sediment and other pollutants are transported downstream, the speed of which is determined by water velocity and stream gradient, leading to quicker downstream transportation in small, high-gradient streams (Broekhuizen and Quinn 1998). Wetland land cover, on the other hand, is largely influenced by an abandoned rail line that occurs in the lower sections of the watershed. This rail line causes significant water retention, increasing the proportion of wetlands in lower sections of the

watershed (Figure 5). Therefore, we believe the main effect observed in PC2 is watershed area, with watershed area influencing the temperature, sediment load, and habitat quality, as shown with PC1.

Figure 5: A map of wetlands and the abandoned rail line within the Caldwell Creek watershed (Dewitz 2023)



Macroinvertebrate community intactness significantly correlated with PC2, however, this was likely an effect of stream size. Macroinvertebrate communities change with respect to stream size; this is a well-studied effect and is largely a result of differential environmental niches (Vannote et al. 1980). Indeed, to combat this, the IBI protocol used for this study has different standardization values for large (≥ 5 th-order) and small streams (≤ 3 rd-order) (Appendix 1) (Bureau of Clean Water 2015). Under this criteria, 4th-order streams are not given classification as large or small streams. For this study, we used the small stream standardization

values for all of our sample sites, however, if large stream standardization values were used, there would likely be a different effect in regards to stream size.

While the NLCD land cover dataset did not show evidence of any significant land cover change from 2001 to 2021, there was still a significant decline in trout abundance for the study region (Table 5) (Appendix 5). Comparing the NLCD land cover classifications with aerial imaging of the study region, we found that the NLCD land cover dataset did not differentiate between recently logged forests and intact forests (Figure 6).

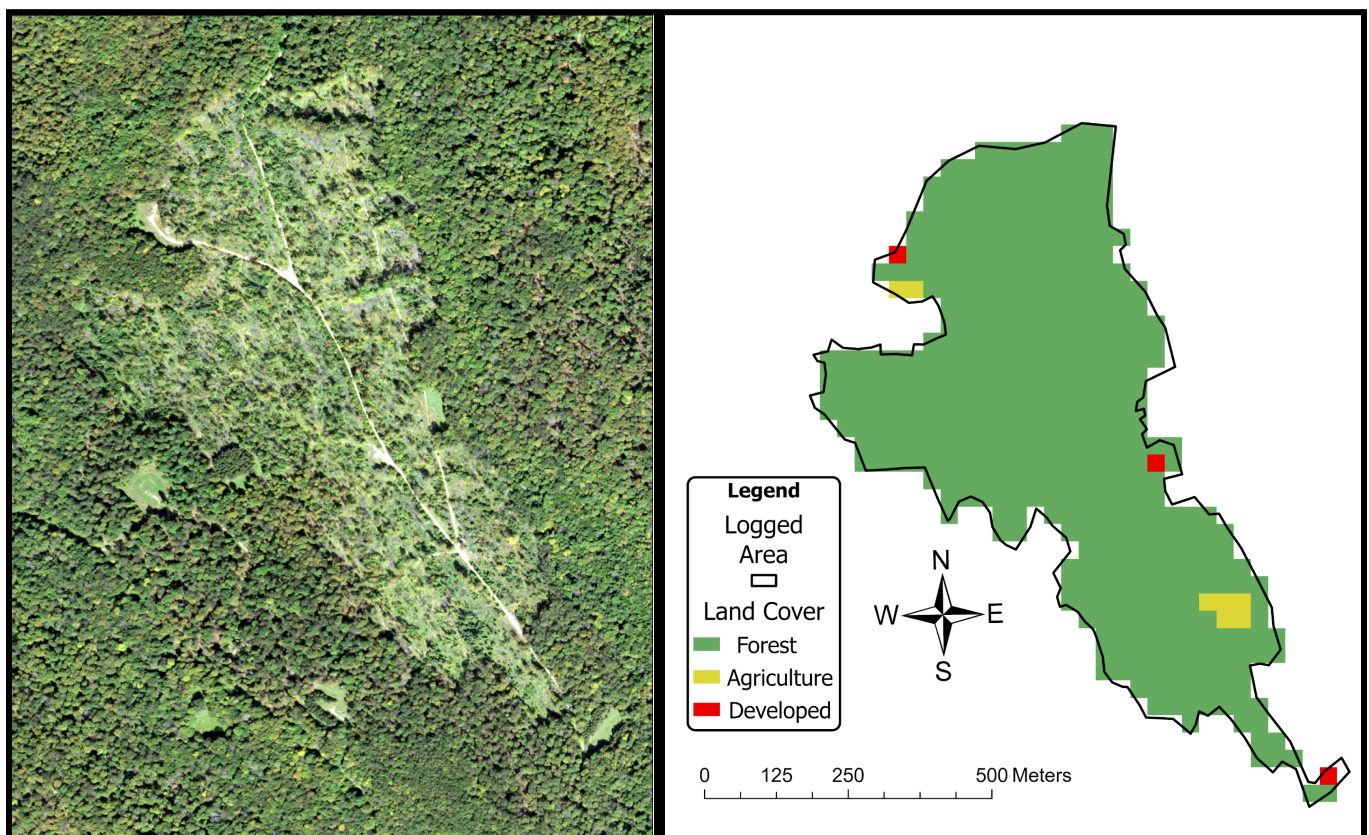


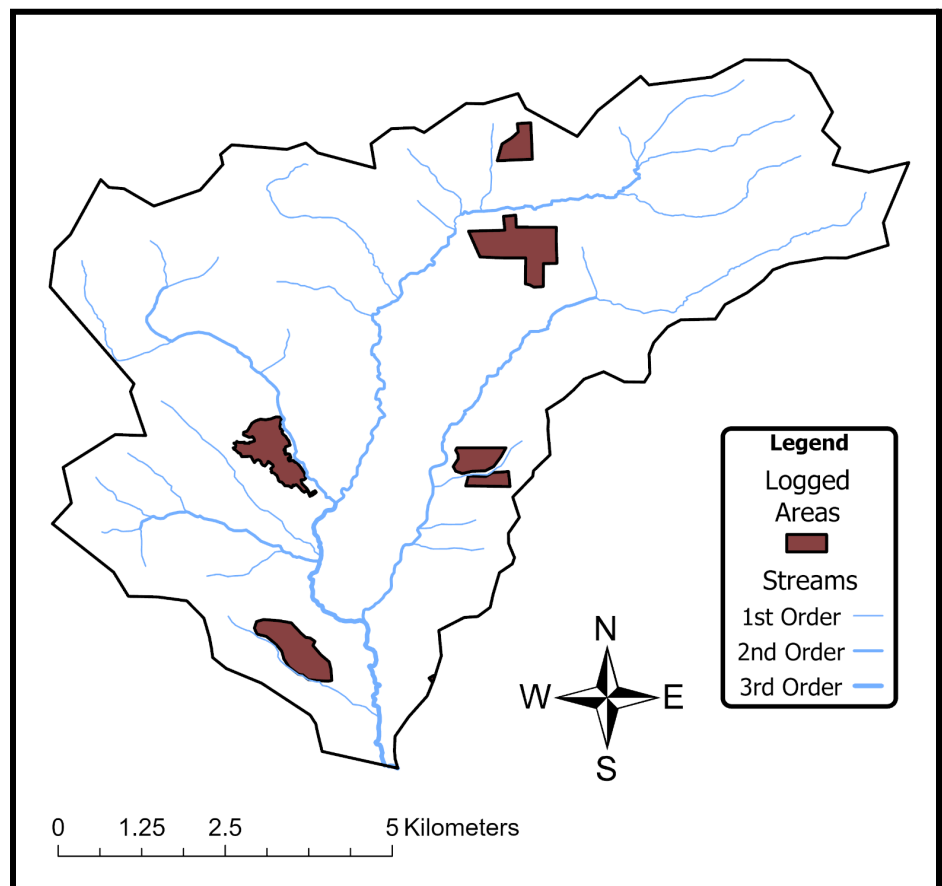
Figure 6: An aerial photograph of a recently logged area within the West Branch of Caldwell Creek watershed, along with its 2021 NLCD land cover classification (Surdex Corporation 2019, Dewitz 2023).

Logging activities are associated with increased runoff and erosion, with previous studies finding significant increases in stream sediment loads after logging (Lewis et. al 2001). As

discussed in the introduction, sediment negatively impacts trout populations through a variety of mechanisms including increased environmental stress, decreased reproductive success, and reduced macroinvertebrate prey density (Ramezani 2014, Redding et al. 1987, Fisher 1963). Additionally, if logging occurs in close proximity to streams (i.e. within the riparian zone), streams that were once protected from solar radiation will absorb additional thermal energy, increasing stream temperature (Fuller et al. 2022). As previously discussed, brown trout are susceptible to high water temperatures, with temperatures above 18.7-19.5°C inducing physiological stress and inhibiting growth and metabolic processes (Elliott and Hurley 2001).

Considering the West Branch of Caldwell, we were able to visually identify 1.9 km² of land that has been logged since 2013, comprising 3.8% of total land cover for the West Branch of Caldwell watershed (Figure 7). These logging activities include both selective-cutting and clear-cutting operations, some of which have occurred on steep slopes, a factor that exacerbates erosion (Fox and Bryan 2000) (Figure 8). Additionally, some of this logging was in close proximity to streams, damaging riparian zones, a factor that can further increase erosion and also cause warming of the stream (Zaimes et al. 2019) (Figure 8).

Figure 7: A map of areas logged in the West Branch of Caldwell Creek watershed since 2013 with streamlines (U.S. Geological Survey 2023B). These logged areas comprise 3.8% of overall watershed area.



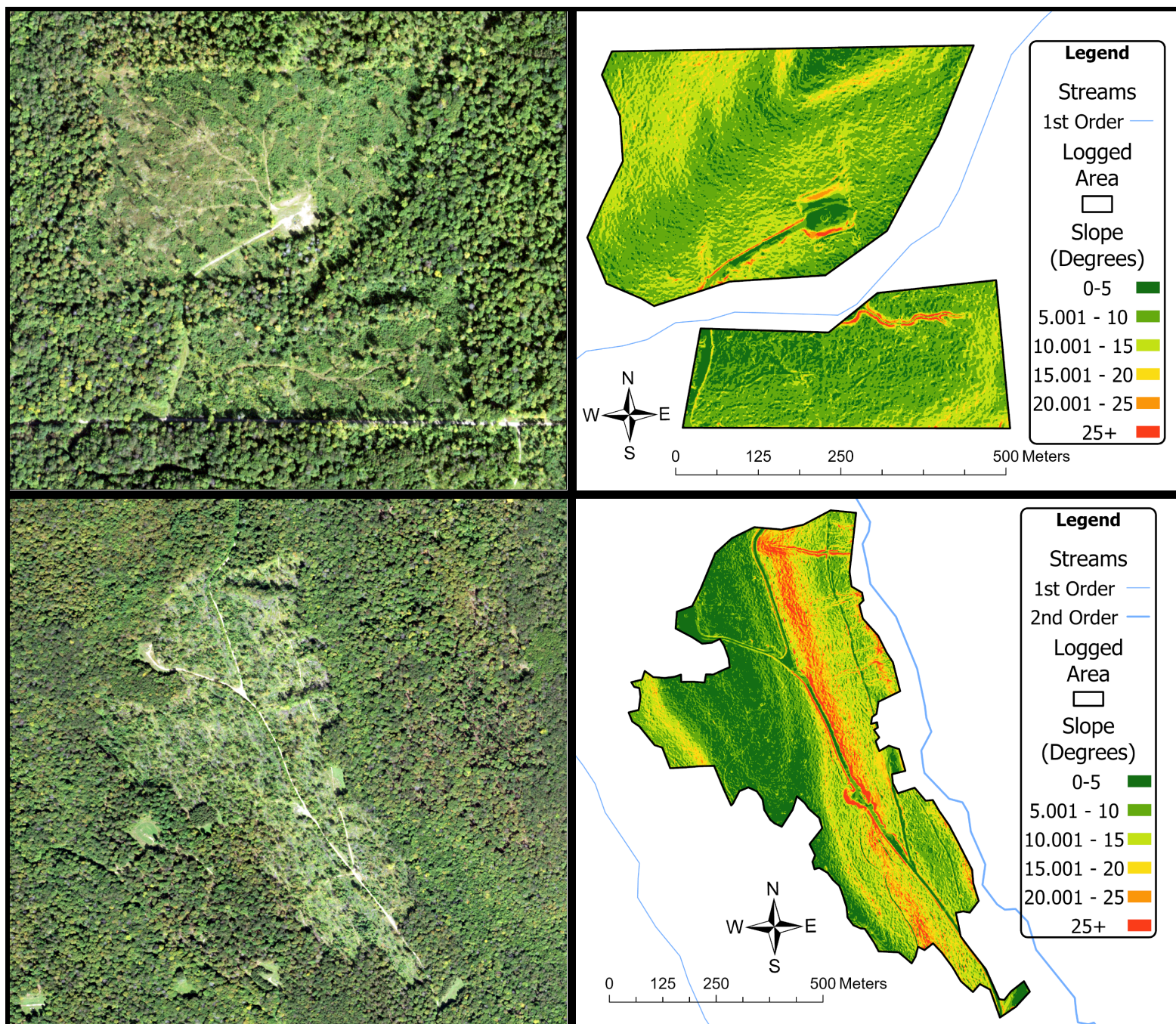


Figure 8: Two aerial photographs of recently logged sites within the West Branch of Caldwell Creek watershed, along with maps of nearby streams and the slope of each logged area (U.S. Geological Survey 2023A, 2023B, Surdex Corporation 2019). The first logged site (top) underwent clearcutting, occurs on flat to moderately steep terrain, and is in close proximity to an unnamed tributary to the Middle Branch of Caldwell Creek. The second logged site (bottom) underwent selective cutting, partially occurred on steep terrain, and is in close proximity to Three Bridge Run, a second order tributary to the West Branch of Caldwell Creek.

While there is no physiological limit for trout in regards to stream-sediment loads, even marginal exposure to fine sediments—especially during the early stages of development—has been shown to not only have detrimental impacts on egg and fry survival but also to have negative impacts to overall fitness (Louhi et al. 2023). We found a significant negative correlation between trout abundance and sediment loads; therefore, if these logging sites are contributing additional sediment into Caldwell Creek, it is safe to assume this would have negative impacts on trout populations.

Seven out of the ten sites included in this study had July average temperatures at or above the temperature threshold above which trout exhibit impaired growth and increased physiological stress (18.7-19.5°C) (Table 6). Interestingly, the West Branch of Caldwell Creek and Pine Creek, two streams that had a high historic abundance of trout, had July average temperatures that

Site	July Average Temperature (°C)	Summer Average Temperature (°C)
Caldwell Creek Mid-Upper	20.8	19.0
Caldwell Creek Mid-Lower	20.8	19.0
Caldwell Creek Upper	20.8	19.0
Caldwell Creek Lower	22.3	20.7
West Branch Caldwell Lower	19.5	17.9
West Branch Caldwell Upper	19.5	17.9
East Branch Caldwell	17.9	16.5
Middle Branch Caldwell	18.5	16.9
Stony Hollow	18.6	17.0
Pine Creek	20.1	18.5

Table 6: Average July and summer temperatures for each sample site.

exceeded this temperature threshold. While an analysis of historic temperature trends within Caldwell Creek is outside of the scope of this study, if historic summer temperatures were cooler than current summer temperatures, this would have negative impacts on trout abundance within Caldwell Creek.

Additionally, we have considered the impact of climate change on the trout populations within Caldwell Creek. Since 1900, mean annual air temperatures have increased by over 1°C in the Northeastern United States. (Kunkel 2013). A study testing trends in stream temperatures in the Delaware and Susquehanna River Basins from 1973-2003 found that the amount of days where stream temperatures exceeded 20 °C was increasing (Kelleher 2009). This likely has compounding effects on any temperature increases caused by logging and land-use patterns. Therefore, it appears likely that these sites have and will become less thermally tolerable for trout with recent climatic events.

This study was limited by the lack of historic sediment and temperature data for the Caldwell and Pine Creek Watersheds, and these are the significant abiotic variables likely attributable to the recent decline in trout abundance. The Pennsylvania Department of Environmental Protection has sampled the West Branch of Caldwell Creek lower site as a part of the Water Quality Network since 1998. This data spans from 1998 to 2004 and from 2010 to 2020 and includes monthly water temperature and suspended sediment measurements for the West Branch of Caldwell Creek lower site (Department of Environmental Protection Water Quality Network Database). Further analysis of this long-term temperature and sediment data will potentially reveal long-term changes to the thermal regimes and sediment loads within Caldwell Creek.

Additional constraints to this study include the limited number of sites that had continuous temperature monitoring during summer months and the limited locations for sediment sampling. Only half of the sample sites in this study had continuous temperature monitoring during the summer months, with non-monitored sites having their temperatures estimated through point measurements. Future monitoring of all sample sites will reveal nuanced differences among sampling sites, and help identify key thermal refugia for trout during the summer months. Sediment was also only monitored from the ten sampling sites, and was not monitored in smaller tributaries. Additional sediment samplings, especially of the tributaries that drain recently logged areas, will give a higher-resolution picture of sediment dynamics within Caldwell Creek. In particular, it will allow for the identification of areas that disproportionately contribute to sedimentation within Caldwell Creek.

The decline in trout abundance within Caldwell Creek is likely attributable to both the effects of increased summer water temperatures and increased stream sediment loads. Climate change is an ever-present threat to trout populations and is expected to reduce cold-water habitats suitable for global trout populations (Wenger et al. 2011). However, reducing the compounding effects of riparian zone disruption can help mitigate the current and future effects of climatic trends (Justice et al. 2017). Stream temperature is largely governed by atmospheric temperature, stream size, groundwater inputs, and the degree of channel shading; of these, humans most directly impact shading of the channel by disturbing riparian canopy cover (Andrews et al. 2022). When riparian vegetation is disturbed, the canopy which previously shaded streams from direct sunlight is disrupted, allowing increased solar radiation to reach and be absorbed into the stream (Justice et al. 2017). Targeted restorations of impaired riparian buffer zones have been

shown to decrease stream temperature, and hence would likely improve thermal conditions for brown trout within Caldwell Creek (Davies-Colley et al. 2009).

Fine sediment at any concentration has been shown to negatively impact trout abundance and fitness. Therefore, mitigating erosion and sedimentation should increase both trout abundance and population resiliency (Louhi et al. 2023). Erosion mitigation techniques such as riparian buffer strips, detention basins, and replanting of native vegetation have been shown to reduce erosion rates from previously disturbed lands (Rickson 2014, Marden 2012).

Additionally, several of the logging sites identified in this study were on steep slopes, in close proximity to streams, and complete clearcutting operations (Figure 8). More sustainable logging practices, such as only logging on relatively flat land, leaving sufficient riparian buffers, and selective-cutting would reduce sedimentation related to logging activities.

Conclusion

The trout populations of Caldwell Creek are in decline, with none of the sample sites harboring sufficient amounts of trout to be classified as a “Class A Wild Trout Fishery” (>40 kg/ha) (Appendix 5). This decline is likely associated with changes to the historic sediment loads and thermal regimes of the region. Further testing on thermal regimes and sediment loads will identify key thermal refugia for protection and will identify areas that are disproportionately contributing high amounts of sediment. Once identified, targeted conservation projects can work to improve riparian zone completeness, reduce warming from solar radiation, and mitigate erosion within logged areas, reducing in-stream sediment loads. While the Caldwell Creek brown trout fishery has a long road to recovery, if attempts are not made to mitigate the effects of warming and sedimentation, it is almost certain that this fishery will decline further.

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Appendix

Metric	Measure	Calculation	Standardization Equation
Total Taxa Richness	Measures overall macroinvertebrate diversity	# of taxa	(Observed value / 33) * 100
EPT Taxa Richness	Measures the diversity of sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) Taxa	# of EPT taxa with a $PTV \leq 4$	(Observed value / 19) * 100
Beck's Index	Measures the presence of very sensitive macroinvertebrate taxa	$3*(taxa_{PTV\ 0}) + 2*(taxa_{PTV\ 1}) + (taxa_{PTV\ 2})$	(Observed value / 38) * 100
Hilsenhoff Biotic Index	Measures the pollution tolerance of the macroinvertebrate community	$(\sum (x*taxa_{PTV\ x})) / \text{total individuals}$	$(10 - \text{observed value}) / (10 - 1.89) * 100$
Shannon Diversity	Measures the evenness of the macroinvertebrate community	$-\sum((taxa\ abundance / \text{total individuals}) * \ln(taxa\ abundance / \text{total individuals}))$	(Observed value / 2.86) * 100
Percent Sensitive Individuals	Measures the abundance of sensitive macroinvertebrate taxa	# of taxa with a $PTV \leq 3$ / total individuals	(Observed value / 84.5) * 100

Appendix 1: Metrics for IBI calculations.

Habitat Parameter	Description
Instream Cover (Fish)	Evaluates the percent makeup of the substrate (boulders, cobble, other rock material) and submerged objects (logs, undercut banks).
Epifaunal Substrate	Evaluates riffle quality, i.e., areal extent relative to stream width and dominant substrate materials (cobble, boulders, gravel) that are present.
Embeddedness	Evaluates the extent to which rocks (gravel, cobble, and boulders) and snags are covered or sunken into the silt, sand, or mud of the stream bottom.
Velocity/Depth Regimes	Evaluates the presence/absence of four velocity/depth regimes (fast-deep, fast-shallow, slow-deep, and slow-shallow).
Channel Alteration	Evaluates the extent of channelization or dredging but can include any other large-scale changes in the shape of the stream channel that would be detrimental to the habitat.
Sediment Deposition	Estimates the extent of sediment effects in the formation of islands, point bars, and pool deposition.
Frequency of Riffles	Estimates the frequency of riffle occurrence based on stream width and thus the heterogeneity occurring in a stream.
Channel Flow Status	Estimates the areal extent of exposed substrates due to water level or flow conditions.
Condition of Banks	Evaluates the extent of bank failure, signs of erosion, or the potential for erosion.
Bank Vegetative Protection	Estimates the extent of stream bank that is covered by plant growth providing stability through well-developed root systems.
Grazing or Other Disruptive Pressures	Evaluates disruptions to surrounding land vegetation due to common human activities.
Riparian Vegetative Zone Width	Estimates the width of natural vegetation from the edge of the stream bank out through the riparian zone.

Appendix 2: WQN Habitat Parameters and their description.

Habitat Parameter	Description
Land-use Pattern Beyond Immediate Riparian Zone	Evaluates land-use patterns beyond the immediate riparian zone that contribute to habitat degradation.
Width of Riparian Zone	Estimates the width of the riparian protective zone from the stream bank to disruptive activities.
Completeness of Riparian Zone	Evaluates the intactness of the riparian zone regarding both vegetative cover and erosion.
Vegetation of Riparian Zone Within 10 m of Channel	Evaluates the density and maturity of the plants that comprise the riparian protective zone.
Debris Dams	Evaluates the quantity and stability of debris dams that fish utilize for foraging.
Channel Width to Depth Ratio	Estimates the degree of channelization within the stream channel.
Channel Bars	Evaluates the presence of channel enlargement and sediment deposition within the stream channel.
Stream-Bank Stability	Evaluates the stability of the stream-bank.
Bank Undercutting	Evaluates the severity of bank undercutting and erosion.
Stony Substrate; Feel and Appearance	Evaluates the angularity and porosity of stream-bed substrates.
Fine Sediment in Riffles and Runs	Evaluates the degree of siltation and sedimentation within riffles.
Riffles and Pools	Evaluates the frequency of riffle and pool habitats.

Appendix 3: RCE habitat parameters and descriptions.

Site	Historic Survey Year(s)	Historic IBI	Current IBI	Change
Caldwell Mid-upper	NA	NA	63.03	NA
Caldwell Mid-lower	NA	NA	58.92	NA
Caldwell Upper	2007	58.82	55.15	-3.67
Caldwell Lower	2000	83.25	73.1	-10.15
East Branch Caldwell	2007, 2009	61.58	62.22	+0.64
Middle Branch Caldwell	2006	89.42	78.73	-10.69
Pine Creek	2008	78.07	63.5	-14.57
Stony Hollow	2007	79.61	74.06	-5.55
West Branch Upper	NA	NA	74.85	NA
West Branch Lower	1999, 2000, 2001, 2002, 2006, 2009, 2014, 2015, 2017, 2018, 2019	80.36	74.32	-6.04

Appendix 4: Current and historic macroinvertebrate IBI scores.

Site	Historic Survey Year(s)	Historic Abundance (#/ha)	Historic YOY Abundance (#/ha)	Historic Biomass (kg/ha)	Current Abundance (#/ha)	Current YOY Abundance (#/ha)	Current Biomass (kg/ha)
Caldwell Mid-upper	NA	NA	NA	NA	3.78	0	1.88
Caldwell Mid-lower	NA	NA	NA	NA	4.65	0	1.76
Caldwell Upper	2010	30	NA	2.83	0	0	0
Caldwell Lower	2010	4	NA	1.29	1.64	0	1.29
West Branch Caldwell Upper	1968, 1969, 1975, 1979, 2009	322.49	178.75	7.02	91.92	58.12	5.93
West Branch Caldwell Lower	1968, 1969, 1978, 1984, 1987, 1996	328	94.67	49.23	12.26	4.59	2.27
Middle Branch Caldwell	2009	516.67	316	NA	281.25	203.13	14.64
East Branch Caldwell	2009	27.86	NA	14	0	0	0
Stony Hollow	2019	132	NA	18.9	54.05	9.01	3.39
Pine Creek	1993	394	130	36.51	4.07	2.04	0.49

Appendix 5: Current and historic brown trout population metrics.

Variable	PC 1 Loadings	PC 2 Loadings
Water Temperature (Field Measurements)	0.26505	0.36286
pH	0.10888	0.029091
Conductivity	0.01428	0.57334
Dissolved Oxygen	-0.42998	-0.21773
Baseflow Turbidity	0.59854	0.12259
Substrate Embeddedness	0.43854	0.53051
High Flow Turbidity	-0.64105	0.35245
July Average Temperature	-0.69244	0.53673
Summer Average Temperature	-0.67271	0.54866
Watershed Area	-0.66109	0.6968
Forest Land Cover	-0.17852	0.22875
Wetland Land Cover	-0.1684	0.65965
Developed Land Cover	0.38083	0.68307
Agricultural Land Cover	0.20324	-0.76643
WQN Instream Cover	0.8755	0.2018
WQN Epifaunal Substrate	0.98879	-0.025817
WQN Embeddedness	-0.41293	-0.12128
WQN Velocity/Depth Regime	0.77894	-0.28049
WQN Channel Alteration	0.95672	-0.10361
WQN Sediment Deposition	0.85126	0.25188
WQN Frequency of Riffles	0.95556	0.026237
WQN Channel Flow Status	0.88093	0.27145
WQN Condition of Banks	0.39128	0.49258
WQN Bank Vegetative Protection	0.88176	-0.069679
WQN Grazing or Other Disruptive Pressure	0.72959	0.057563
WQN Riparian Vegetative Zone Width	0.92304	-0.089223
RCE Land-Use	0.35252	0.7885
RCE Riparian Zone Width	0.88579	0.1747
RCE Riparian Completeness	0.88524	0.094518

RCE Riparian Vegetation	0.35252	0.7885
RCE Debris Dams	0.77162	-0.26269
RCE Channel Bars	0.77198	0.12436
RCE Stream-Bank Stability	0.91865	0.11323
RCE Bank Undercutting	0.81775	-0.065253
RCE Stony Substrate	0.96678	-0.018781
RCE Fine Sediments	0.97935	-0.18182
RCE Riffles and Pools	0.94452	-0.029157

Appendix 6: Variable loadings for PC1 and PC2.

Predictor Variable	Response Variable	Equation	R ²	<i>p</i> -value
PC1	Trout Abundance	$45.89 + 11.79x$	0.36	0.0004
PC1	YOY Trout Abundance	$28.74 + 8.69x$	0.37	0.0003
PC1	Trout Biomass	$3.25 + 0.56x$	0.33	0.0007
PC1	Macroinvertebrate IBI	$67.57 + 0.67x$	0.09	0.1306
PC2	Trout Abundance	$45.89 - 15.31x$	0.18	0.0166
PC2	YOY Trout Abundance	$28.74 - 8.8x$	0.11	0.0629
PC2	Trout Biomass	$3.25 - 0.8x$	0.2	0.0117
PC2	Macroinvertebrate IBI	$68.1 - 2.61x$	0.32	0.0019

Appendix 7: Principal components as predictors of biotic metrics.