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A comparison of riparian characteristics and resulting water quality in restored agricultural systems

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A Comparison of Riparian Characteristics and Resulting Water Quality in Restored Agricultural Systems

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Abstract

Agronomic land use and urbanization are the leading causes of water quality decline within streams of the Shenandoah Valley. Implementation of riparian buffer zones is a common, beneficial approach to initiate restoration of negatively affected waterways. In the Commonwealth of Virginia, the Conservation Reserve Enhancement Program (CREP) assists landowners in repairing natural habitat through the provision of cattle fencing and reintroduction of hardwood trees, native warm season grasses, and shrubs. We analyzed seven CREP restored sites of varying time since restoration (5-15 years) to determine the effects of time, land use, and riparian zone characteristics on water quality. The Virginia Stream Condition Index (VA-SCI), Hilsenhoff Biotic Index (HBI), and Shannon Weiner Diversity Index (H) were used to infer water quality through the use of site-specific benthic macroinvertebrate identification. The percent forest, agricultural land, and impervious surfaces in watershed and 100 meter buffer areas for each site was calculated through GIS analysis. Riparian characteristics were determined through in-field assessment of overhanging vegetation, amount woody debris, number of riffles, average number of woody specimens (per m^2), and average diameter-at-breast height (DBH). Single variable regressions showed no significant relationships between the macroinvertebrate index scores and the tested variables with the exception of woody debris presence. The amount woody debris was shown to possess a negative relationship with the VA-SCI, with a significant R^2 value of 0.669 and p-value of 0.025. Unexpectedly, a lower amount woody debris predicted higher water quality. Through stepwise, multiple variable linear regression tests, we found that varying combinations of riparian characteristics (lower amounts woody debris, greater average DBH of riparian trees, greater time since restoration, and lessor percent impervious surfaces) were significant predictors of macroinvertebrate index scores, all with adjusted R^2 values above 0.763. Though the majority of these results were consistent with our predictions, it should be noted that the sample size of this study was small; an increased sample size and more rigorous vegetation assessment may provide more substantial results in the future.

Introduction

The declining condition of Virginia's natural aquatic systems requires immediate action to halt degradation and restore ecological function vital to the longevity of biodiversity. Increases in pesticide use, polluting runoff, and deforestation have had deleterious consequences on the quality of the abiotic stream components that foster the growth, health, and survival of the inhabiting biota. In the Shenandoah Valley, agronomic land use and urbanization are major threats to alluvial ecosystems. Waterways that flow through agricultural land, or those within highly agronomic watersheds, often receive direct inputs of fertilizing chemicals due to runoff and groundwater flow. The resulting inflated levels of nitrogen, phosphorous, and other nutrients are associated with fish kills, macroinvertebrate diversity and abundance decline, microorganism decreases, adverse macrophyte growth, and the associated negative effects on community structure within the affected body of water (Schafer, et al., 2007). Impervious surfaces are an additional concern for streams located in urban areas due to high population density and infrastructure; heavy sediment and pollutant loads not absorbed or filtered by soil culminate in the waterways (Feio, 2013). The removal and clearing of natural vegetation, including trees, for cropland, or via livestock grazing, also have significant effects on habitat decline as vegetation in the riparian zone acts to filter polluting nutrients, prevents erosion of sediment into streams, provides shade for temperature regulation, and serves as a haven for organisms crucial to community structure. Combating this anthropogenic deterioration, however, can be difficult and often requires a multi-step approach to return a body of water to its natural state. Restoration of the aquatic network and surrounding land is a common beneficial approach to conserve and maintain affected habitats.

In most cases, it is not possible to return an affected waterway to its previous condition once it has degraded; however, methods of restoration have proved beneficial in reestablishing operating efficiency in communities over time. Ecological restoration is the reestablishment of processes, functions, and related biological, chemical, and physical linkages between the aquatic and associated riparian ecosystems (Kauffman, et al., 1997). The process begins with identification of the problem, followed by strategies for mitigation. Passive restoration, or the halting of detrimental activities, is sometimes enough to allow the ecosystem to repair itself over time; this may include cessation of livestock grazing and/or reintroduction of natural flow. If these changes are not shown to improve environmental conditions, active restoration may be needed. Active restoration encompasses acts of human involvement that initiate repair, including the reintroduction of species (animal and plant), placement of objects such as woody debris that facilitate the growth of microhabitats, or removal of artificial structures that hinder natural channel morphology.

Once a restoration has been initiated, monitoring of the selected site should take place to track improvement. Physical characterization includes observation of general land use, summarization of the riparian vegetation features, and measurements of stream parameters such as width, depth, flow, and substrate type (Barbour, et al., 1999). Typically, habitat evaluations are conducted *in situ* multiple times over the course of a predetermined time period to analyze progress of the restoration efforts. Once assessments have been made, quality status can be computed through comparison of the actual observations and those expected from physically similar reference sites (Feio, et al., 2015).

Restoration of agricultural water bodies in Virginia are largely initiated by the Conservation Reserve Enhancement Program (CREP), which aims to improve water quality by offering participating farmers financial incentives (Virginia DCR, 2016). The program assists private landowners in restoring a minimum of 100 feet of riparian buffer through the reintroduction of hardwood trees, native warm season grasses, and approved shrubs. Over 39 million acres of land have been restored through CREP nationwide.

Riparian Zone Characteristics Influencing Stream Health

When assessing restoration effects on water quality over time, characteristics of stream flow and composition, riparian vegetation, organismal assemblages, and the surrounding landscape are often measured. Due to the complex and interdependent relationships between abiotic and biotic components of an ecosystem, one or multiple variables within a natural system may hold strong predictive power over others.

Alluvial networks are comprised of a series of pools and riffles based on channel morphology (depth, slope, and discharge), which vary in substrate composition, method of formation, and quantity within a reach (Brown and Brussock, 1991). An increased frequency of riffles indicates diversity within an aquatic community due to the high-quality habitat provided (Barbour, et al., 1999). Further, Brown and Brussock (1991) compared benthic assemblages in upstream and downstream riffles and pools, and found that all identified taxa were most abundant in riffles. Thus, a greater number of riffles and pools within a waterway may support a more diverse community of biota, and may correlate with higher water quality.

Coarse woody debris present within streams often takes the form of fallen, dead trees, large branches, and chunks of wood present due to downstream travel or streamside vegetation deposit. The occurrence of woody debris can influence both stream flow and path, and are main constituents of ecosystem services, providing both habitat for aquatic and stream-dwelling organisms as well as facilitating nutrient cycling and transport (Harmon, et al., 1986). Further, the presence of large woody debris in low gradient streams of Virginia has been shown to increase pool formation and area, and increase the presence of the sensitive macroinvertebrate taxa, Ephemeroptera (Hilderbrand, et al., 1996).

An additional beneficial component to stream health, as both a regulatory and depository element, is riparian-generated overhanging vegetation. Tree canopy features that extend beyond stream bank edges, for example, branches, leaves, and vines, are crucial in terms of shade provision and resultant temperature control. Biota present within water bodies, particularly the iconic eastern Brook trout, depend on cool environments for essential ecological functioning (Barton, et al., 1985). In addition, primary producers, like algae and aquatic macrophytes, are influenced by sun exposure; without the presence of overhanging vegetation, waterways are susceptible to an overgrowth of aquatic vegetation, which can disrupt balanced nutrient cycling and skew water pH leading to anoxic conditions (Klopatic, 1977). Furthermore, the allochthonous deposits and detrital inputs transferred via overhanging leaves and branches are crucial for macroinvertebrate feeding and the resulting proper nutrient exchange (Knight and Bottorff, 1984). Vegetation that lies above bodies of water fan also facilitate the life cycle of holometabolous insects that require both aquatic and terrestrial habitat; adults will often lay their eggs on leaves above streams, which then fall into the water, allowing aquatic larvae to hatch and thrive (Huryn and Walace, 2000).

Characteristics of riparian buffer composition have an immense impact on stream health. Measurements of vegetation structure, including density and height of woody specimens, reflect the presence of valuable resources useful for temperature regulation, water filtration, allochthonous deposits, erosion control, and habitat for local organisms; a greater abundance of trees offers greater ecological benefits. Similarly, the larger the crown width of a tree, the greater the amount of potential allochthonous deposits and shade; this measure can be estimated through assessing the diameter at breast height (DBH) of the trees and is independent of site, crown class, and species (Minckler and Gingrich, 1970). Height of vegetation in a riparian buffer, moreover, is used to estimate biomass through modeling (Lefsky, et al., 2005). Like that of density, a greater biomass of vegetation in an area relates to a greater ability to provide resources necessary for environmental functioning.

The physical and biotic characteristics that influence water quality are greatly interdependent and dynamic. With increasing age, riparian forest vegetation grows in height, fullness, abundance and density thus increasing the beneficial processes facilitated. After the implementation of riparian restoration, water quality is therefore expected to improve.

The Role of Benthic Macroinvertebrates in Streams

In order to supplement measurements of physical characteristics and water quality, biological surveys of taxa richness are recommended (Barbour, et al., 1999). Macroinvertebrates are excellent indicators of stream health due to their sensitivity and quick life cycles; these organisms play a key role in decomposition of allochthonous material, productivity, nutrient cycling and energy transfer in the ecosystem (Feio, et al., 2015). Moreover, macroinvertebrates tend to be stable inhabitants of a stream, persisting through minor disturbances, such as rainfall, and can thus be used as more constant indicators of water quality over time. It is widely understood that a greater abundance of sensitive organisms and greater diversity of species reflects healthy water; species richness is said to increase with spatial heterogeneity along a reach due to differing niches within a body of water (Hawkins and Vinson, 1998). Thus, when harsh conditions due to anthropogenic pollution, or scouring due to flood, affect a waterway (and the conditions deviate from “normal”), it can only be expected that a few tolerant species will prevail, reducing the species richness and homogenizing the population.

Macroinvertebrate community structure, therefore, can indicate water quality. A greater abundance, diversity, and presence of sensitive species are correlated with greater stream health as deduced through the use of metric indices. The Virginia stream condition index (VA-SCI) is a bioassessment metric used to indicate water quality and detect impairments based on identified biotic assemblages. The VA-SCI utilizes species richness, abundance, and diversity information to measure overall responses of communities to environmental stressors (Burton and Gaerristen, 2003). Other commonly used indices include the Shannon Weiner Diversity Index (H), and Hilsenhoff Biotic Index (HBI), and Ephemeroptera-Plecoptera-Tricoptera Index (EPT). These indices simplify complex biological data and yield scores that pertain to water quality, useful for comparison (Angradi, et al., 2009). The Shannon Weiner diversity index is used to calculate diversity based on the number of species present, while the HBI assigns tolerance values to specific species, yielding overall community resistance to pollution (Lenz and Miller, 1996). The EPT uses species richness of particularly sensitive species to assign an additional resistance value to the stream in question.

Landscape Characteristics Influencing Stream Health

In addition to localized riparian degradation, elements of the landscape surrounding a stream network can greatly influence water quality. As mentioned previously, agricultural land and impervious surfaces facilitate the deposition of pollutants in waterways, as rain and groundwater wash pesticides, excretion-based waste, de-icing salt, and an excess of surface water from high elevations to low elevations. An increased watershed area, therefore, encompasses a greater network of streams and a greater potential input of deposits to higher order waterways. Through Geographic Information System (GIS) analysis, assessments of land use at both the watershed and riparian buffer levels can be utilized to detect large and small-scale effects on stream health.

Hypothesis and Predictions

The aim of this study is to determine whether time and physical measures of riparian zones within the Shenandoah Valley can be used to predict water quality as measured by benthic macroinvertebrate surveys. The study will be based on seven CREP restored sites of assorted time since restoration (5-15 years). We hypothesize that restored streams with a greater number of riffles and input of woody debris, a higher density and DBH of woody stems, and a greater time since restoration will possess better water quality and be able to predict trends in macroinvertebrate index scores. Additionally, watersheds for each stream that have the least agricultural land use and impervious surfaces are expected to have the best quality of water.

Methods

Site Selection

Seven CREP sites within the Shenandoah Valley, Virginia were chosen based on time since restoration implementation, stream condition, and owner agreeability (Figure 1). Contact information for property owners of CREP participating sites were received through the Shenandoah Soil and Water Conservation District. Each owner was contacted both to receive permission to conduct research on their land, and for a rudimentary assessment of stream condition; sites of varied time since restoration (5-15 years), and those deemed viable for assessment (stream accessible, streamflow present, and cattle fencing in place) were chosen. A range of restoration times was selected to most accurately represent developments in riparian and stream characteristics after active restoration execution.

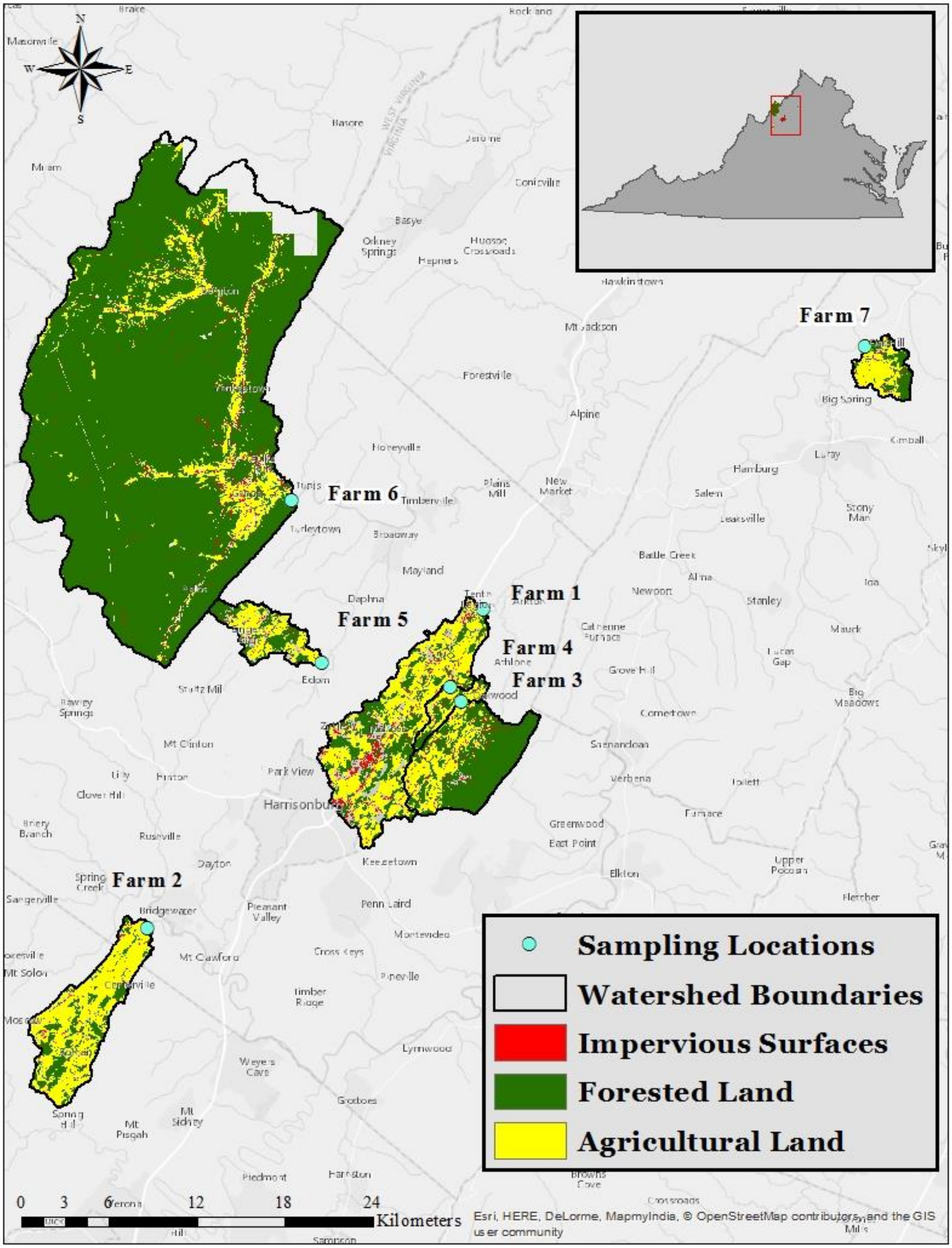

Figure 1. Map displaying the seven CREP farm sampling locations and the corresponding watersheds. Land cover is symbolized by color.

Sampling Methodology

The following *in situ* assessments were conducted or recorded at each CREP site: benthic macroinvertebrate collection, riffle number, amount overhanging vegetation, amount woody debris, abundance of woody specimens, density of woody specimens, and DBH of woody specimens. Each stream sampling location was determined based on a collaborative 2016 study assessing water quality at 12 CREP sites in the Shenandoah Valley (Thady, 2016). Using a Trimble GeoXT GPS, sampling site coordinates from the 2016 study were loaded into ArcMap and a National Hydrogophy Dataset (NHD) layer scaled at 1:24000 and containing rivers and streams in the state of Virginia was then added. A 50-meter buffer was created on either side of each sample site using the Buffer tool to represent the riparian buffer zones at each location (*SiteNumber_NHD_buffer*). The Create Random Points tool was then implemented to generate 10 random way-points within the created buffer zones, and the coordinates were then uploaded to the GeoXT GPS to locate in the field (Figure 2). The random points indicated areas in which riparian vegetation sampling would occur; randomization within the riparian zone ensured an unbiased representation of the entire 100 m^2 buffer around the stream sample site.

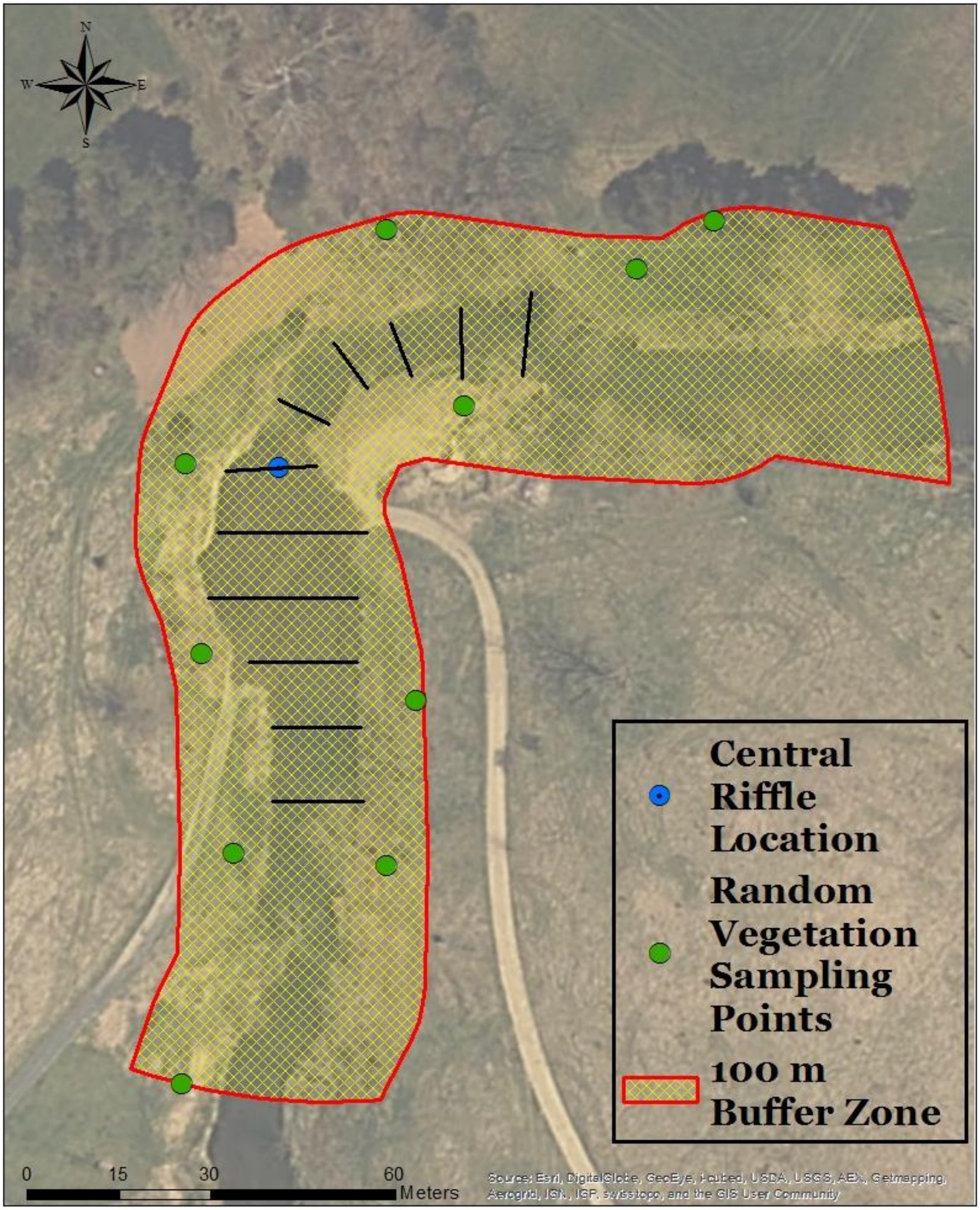

Figure 2. Map displaying the GIS-generated 100-m buffer zone for farm 1 with the central riffle location in blue, and 10 random vegetation sampling points in green. The 10-m increment locations for woody debris and overhanging vegetation assessment are displayed as black lines.

At each of the seven CREP sites, macroinvertebrates were collected at the specified riffle coordinates denoted by the handheld GPS. A total of one riffle was sampled at each site. A 1m x 1m kick-net sampling method (500 µm mesh size) was implemented for a total of two minutes; the first minute was used to dislodge organisms from aquatic vegetation and streambed through sediment disruption, and the remaining minute was spent scraping rocks by hand to free any clinging invertebrates. The collected specimens were then preserved in 70% ethanol to prevent rapid desiccation and transported to a laboratory.

The number of riffles 50m upstream and 50 m downstream of the central sampling riffle at each of the seven field sites was counted. At each 10 m increment of the 100 m stretch, the presence or absence of overhanging vegetation and number of woody debris within the stream was recorded. A summation of each observed measure was calculated and documented for each site.

The abundance and DBH of woody specimen within the riparian buffer zones of each site were also measured to gauge differences in vegetation growth between sites. Tree measures were taken at each of the ten random locations specified through GIS. A handheld GPS was used to navigate to each random location, where surveyors placed one end of a measuring tape at the designated coordinate, and walked in a circle 5 m in diameter. The number and DBH of woody specimen greater than 1 m in height present within each 78 m^2 area (0.0078 hectares) were recorded. Averages of tree abundance and DBH were calculated for each site.

The macroinvertebrates collected at each sampling location were identified in the laboratory. The sample of macroinvertebrates from each site was emptied onto a tray possessing 12 numbered squares of equal area. Using a 12-sided die, researchers removed organisms from designated squares until at least 200 were imputed into the "subsample." Subsample macroinvertebrates were identified to the family level with the use of a dissecting microscope (Voshell, 2002 and Benthic macroinvertebrate key, 1995). Identifying to the family level, compared to genus or species, is the preferred method in Europe, Australia, and the USA because it is safe, less error-producing, and accurately quantifies the wide distribution of benthic organisms needed to assess water quality (Feio, et al., 2015). The number of organisms within each family at each site was then entered into an excel spreadsheet to calculate the HBI, VA-SCI, and Shannon Diversity indices.

GIS Analysis

GIS analysis was used to calculate watershed area, and percentage land use for the watershed and buffer zones of each sampled site (Figure 1). Sources of the data used to create these layers are listed in Table 1. Central riffle coordinates, as motioned above, were used as representative site points. The site points were projected to the *Albers_Conical_Equal_Area* projection using the Project tool ("*SiteNumber_proj").* Flow direction and flow accumulation layers ("*SiteNumber_FDR_proj*" and "*SiteNumber_FAC_proj*") were then added and inputted into the Watershed tool, using the sample point as a pour point, to generate the watershed stream network flowing into the sample site (*"SiteNumber_wtshd").* The area of each watershed was calculated to assess potential relationships with macroinvertebrate index scores. The watershed layer was then used as a mask to clip the stream and 100 m stream buffer zones ("*NHD_2017" and "SiteNumber_NHD").*

To assess land use within watershed and buffer areas, the watershed and stream buffer layers were projected to the *NAD 1983 HARN StatePlane Virginia North FIPS 4501* projection. A 1 m x 1 m land cover raster was then downloaded from the Virginia Geographic Information Network and run through the Extract by Mask tool for each watershed and buffer zone

(“*SiteNumber_LU_wtshd”* and “*SiteNumber_LU_buffer”)*. Within this layer, impervious surface cells were categorized by the numbers 21 and 22, agricultural land use by 81 and 82, and forested land use as 41 and 42. The percentage of each land use class was calculated for both buffer and watershed zones, by dividing the land use area by total area (in km^2).

Table 1. Data used to generate landscape variables used for GIS analysis.

File	Type	Description	Source
Flow Direction Raster	.tif	Layer containing flow direction between cells. Used in the Watershed tool to delineate stream flow and determine watershed areas.	NHDPlus Version 2, 2012.
Flow Accumulation Raster	.tif	Layer containing flow accumulation between cells (the number of cells draining into each cell). Used in the Watershed tool to delineate stream flow and determine watershed areas.	NHDPlus Version 2, 2012.
NHD Stream Layer	.shp	Layer containing all waterways within the state of Virginia at the scale of 1:24000. Used to generate 100 m buffer zones for each site.	U.S. Geological Survey, 2013.
Land Use Raster	.tif	1 m land cover data for the state of Virginia. Used to assess percent land cover in watershed and buffer areas of each site.	Virginia Geographic Information Network. 2017.

Statistical Analysis

Linear regression tests were run with SPSS statistic software (version 23) to determine potential relationships between variables, both separately and combined. Single variable linear regression tests were conducted to assess relationships between time, riparian characteristic measures, percent land use for both watershed and buffer areas, and macroinvertebrate index scores. Resulting R^2 and p-values were recorded to assess predictive power between variables.

Bivariate correlations and scatterplot matrices were explored prior to execution of multiple linear regression tests to determine if any two variables were strongly correlated. Significant positive or negative values were used as indicators of high correlation, and if present, one of the two variables was removed from any analyses in which they were combined. Stepwise multiple linear regression tests were run to evaluate significant relationships between combined groupings of independent variables and dependent variables. The adjusted R^2 and p-values were again recorded.

Results

Macroinvertebrate Index Comparisons

Macroinvertebrate index scores for the seven CREP farms were highly varied (Table 2). Farm 6 (seven years restored) had the highest water quality as denoted by all three indices, possessing the highest VA-SCI (64) and H values (2.25), and the lowest HBI value (4.5). Farm 5 (five years restored) had the lowest water quality also indicated by the three indices, possessing the lowest VA-SCI (28) and H values (0.75), and the highest HBI value (7.4).

Five of the seven sample sites had "impaired" water according to the Biosurvey Category system of the VA-SCI, with values lower than 61.3 (Farms 1, 3, 4, 5, and 7). The remaining two farms (farms 2 and 6) were classified as "least impaired" with VA-SCI values between 61.4 and 81.6. No farms were found to have "exceptional" water quality (VA-SCI values above 81.6).

Table 2. Summary of in-field sampling and GIS analyses. Total abundance of macroinvertebrates for each site were counted but excluded from statistical analysis.

Farm Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Sample Number	72	70	74	73	69	75	71
Restoration Year	2002	2011	2006	2002	2011	2009	2001
Years Restored	14	5	10	14	5	7	15
HBI	5.2	5.0	4.6	4.6	7.4	4.5	5.1
VA-SCI	54	63	57	59	28	64	49
Shannon Diversity	1.81	2.31	2.18	1.94	0.75	2.25	1.64
Total Abundance (#/m^2)	367	614	362	711	457	394	352
Area of Watershed (m^2)	125906000	44606700	44487900	52097400	18218700	472041000	12143700
% Impervious (Watershed)	5	3	3	4	3	1	3
% Forest (Watershed)	43	24	66	62	38	90	36
% Agriculture (Watershed)	42	69	27	31	49	7	56
% Impervious (Buffer)	5	3	5	5	4	3	6
% Forest (Buffer)	47	21	69	64	34	84	23
% Agriculture (Buffer)	41	71	22	28	51	10	65
Overhanging Vegetation (#/11)	5	5	5	11	9	9	11
Amount Woody Debris (per 100 m)	15	7	18	3	24	1	15
Number of Riffles (per 100 m)	4	8	4	10	2	2	14
Average Number of Woody Stems (per ha)	0.03	0.04	0.05	0.04	0.03	0.05	0.14
Average DBH (cm)	14.8	13.3	9.2	15.9	15.3	14.2	11.1

Riparian Characteristic Comparisons

Measured riparian characteristics (amount overhanging vegetation, amount woody debris in the stream, number of riffles, the average number of trees, and the average DBH) between the seven sample locations were compared (Table 2). The amount overhanging vegetation between sample locations ranged from 45% -100% coverage; of the eleven 10-m increments analyzed for overhanging vegetation, each farm had between 5 to 11 occurrences. The amount woody debris within each stream ranged from 1 to 24 pieces total throughout the 100 m stream stretch, also recorded based on 10-m increment observations. Farm 5 had the highest amount of woody debris, while farm 6 had the lowest. Riffle number ranged from 2 to 14 throughout each 100-m stretch, with farm 7 possessing the highest number of riffles and farms 5 and 6 possessing the lowest. The average number of trees within each riparian zone, ranged from 0.03 to 0.14 trees per square meter (0.000003 to 0.000014 stems per hectare). Farms 1 and 4 had the lowest average number of trees, while farm 7 had the highest. Finally, the average DBH of measured trees per site ranged from 9.2 to 15.9 cm. Farm 3 had the lowest DBH, and farm 4 had the highest.

Land Cover and Watershed Area Comparisons

The percent forested land, agricultural land, and impervious surfaces were calculated for both watershed and buffer zones for each of the seven CREP farms (Table 2). All watersheds possessed less than 5% impervious surface. Agricultural land comprised between 7% and 69% of all watersheds, and forested land ranged from 24% to 90%. Impervious surface within buffer zones for all sites were less than 7%. Agricultural land cover ranged between 10% and 71%, while forested land cover ranged between 21% and 84%. Land cover distributions can be seen in Figure 2.

Watershed area greatly varied between sites (Table 2). Farm 6 had the largest watershed with an area of 472,041,000 m^2, while farm 7 had the smallest watershed with an area of 12,143,700 m^2. The watersheds of Farms 3 and 4 were located within the watershed of Farm 1 (Figure 1).

Single Variable Linear Regression Results

Single variable linear regression tests did not yield significant relationships between any of the following variables: 1) macroinvertebrate index scores and years restored; 2) macroinvertebrate index scores and land cover; 3) macroinvertebrate index scores and watershed area; 4) macroinvertebrate scores and riparian characteristics (with the exception of amount woody debris); and 5) riparian characteristics and years restored (Table 3, 4). The amount woody debris was shown to significantly predict VA-SCI scores, with an R^2 values of 0.669 and p-value of 0.025 (Figure 3). Counterintuitively, a lower amount woody debris predicted higher water quality through increased diversity and species richness of macroinvertebrates.

Table 3. Results of single variable regression tests. Independent variables are listed in the far left column and dependent variables are listed as column headers. The direction of the correlations are noted in parenthesis after the R^2 values. Significant relationships (p-value < 0.05) are bolded in red.

R^2 Values and Correlation Directions			
	HBI	**VA-SCI**	**H**
Years	0.165 (-)	0.024 (+)	0.007 (+)
Overhanging Vegetation	0.011 (+)	0.065 (-)	0.135 (-)
Woody Debris	0.517 (+)	**0.669 (-)**	0.513 (-)
Riffles	0.094 (-)	0.029 (+)	0.016 (+)
Avg. Trees	0.037 (-)	0 (-)	0 (-)
Avg. DBH	0.110 (+)	0.030 (-)	0.107 (-)
Watershed Area	0.131 (-)	0.199 (+)	0.155 (+)
% Impervious (Watershed)	0.022 (+)	0.066 (-)	0.076 (-)
% Forest (Watershed)	0.223 (+)	0.155 (+)	0.134 (+)
% Agriculture (Watershed)	0.15 (+)	0.093 (-)	0.074 (-)
% Impervious (Buffer)	0 (-)	0.084 (-)	0.087 (-)
% Forest (Buffer)	0.232 (+)	0.177 (+)	0.159 (+)
% Agriculture (Buffer)	0.157 (-)	0.103 (-)	0.089 (-)

Table 4. Results of single variable regression tests assessing riparian characteristics and time. "Years Restored" is the independent variable and dependent variables are listed in the far left column. The direction of the correlations are noted in parenthesis after the R^2 values. There were no significant relationships among these variables.

R^2 Values and Correlation Directions	
	Years Restored
Overhanging Vegetation	0.089 (+)
Woody Debris	0.002 (-)
Riffles	0.585 (+)
Avg. Trees	0.221 (+)
Avg. DBH	0.012 (-)

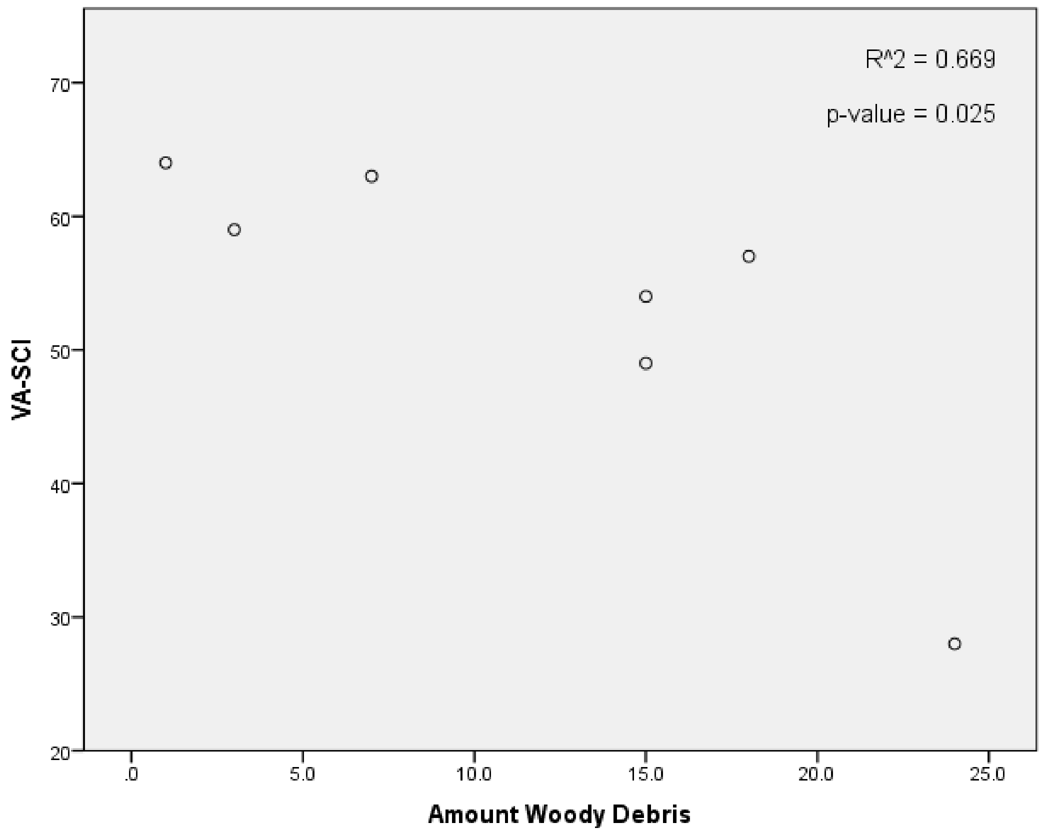

Figure 3. Scatter plot of the results of the single variable linear regression showing the significant relationship between the VA-SCI and amount woody debris.

Multiple Variable Linear Regression Results

Prior to multiple variable linear regression tests, bivariate correlations were run to determine if any two variables were strongly associated with one another. Percent agricultural and forested land cover for both buffer zones and watershed areas were highly, negatively correlated (-0.993 and -0.997 respectively). In addition, years restored and percent impervious surfaces for buffer zones specifically were highly, positively correlated (0.852), despite no obvious connection between these measurements. Percent forest land cover and percent impervious surfaces (in buffer zones) were thus removed from regression tests to minimize the potential for inflated predictive power. Surprisingly, amount woody debris and watershed area were not significantly correlated (-0.589), though we expected an increased watershed stream network to facilitate increased transport of upstream material. Stepwise, multiple variable regression analyses were then conducted to test the relationships between macroinvertebrate index scores and the following groups of independent variables: 1) riparian characteristics; 2) riparian characteristics and time; 3) riparian characteristics, time, and buffer land cover; and 4) riparian characteristics, time, watershed area and watershed land cover. Significant relationships (p-value < 0.05) between variables are shown in Table 4.

Table 4. Significant adjusted R^2 and p-values from stepwise, multiple variable regression tests with correlation directions listed in parenthesis. Regression 3 did not yield significant relationships and was thus omitted from the table.

Significant Adjusted R^2 Values			
Independent Variable Grouping	**Dependent Variable**	**Adjusted R^2**	**p-value**
1: Riparian Characteristics			
Woody Debris (+) Avg. DBH (+)	HBI	0.763	0.025
Woody Debris (-) Avg. DBH (-) Overhanging Vegetation (-)	VA-SCI	0.933	0.010
Woody Debris (-) Avg. DBH (-) Overhanging Vegetation (-)	Shannon Diversity	0.970	0.003
2: Riparian Characteristics and Years Restored			
Woody Debris (+) Avg. DBH (+) Avg. Number of Trees (-) Years Restored (-)	HBI	0.980	0.013
Woody Debris (-) Avg. DBH (-) Overhanging Vegetation (-) Years Restored (+)	VA-SCI	0.998	0.001
Woody Debris (-) Avg. DBH (-) Overhanging Vegetation (-) Years Restored (+)	Shannon Diversity	0.993	0.005
4: Riparian Characteristics, Years Restored, Area, and Land Use (Watershed)			
Woody Debris (+) Avg. DBH (+) % Impervious (+) % Agriculture (+)	HBI	0.997	0.002
Woody Debris (-) Avg. DBH (-) Overhanging Vegetation (-) %Impervious (-)	Shannon Diversity	0.995	0.004

The amount woody debris and average DBH were present in all significant multiple variable regression tests. Regression 2 additionally included years restored in all significant relationships with macroinvertebrate scores, and regression 4 additionally included percent impervious surfaces. The VA-SCI could not be significantly predicted by the combination of riparian characteristics, time, and watershed land use. Furthermore, none of the macroinvertebrate index scores could be predicted by the combination of riparian characteristics, time, and buffer land use.

Discussion

The aim of this study was to determine whether characteristics of time, riparian buffer zones, and surrounding landscapes could be used to predict water quality through benthic macroinvertebrate community compositions in seven CREP farms of varying time since restoration. The HBI, VA-SCI, and H indices were used to quantify water quality based on macroinvertebrate abundance and diversity within each sampled site. Characteristics measured to represent riparian buffer zone composition included amount overhanging vegetation, amount woody debris present in the stream, number of riffles, average number of trees, and average DBH per site. We calculated the percent forested land, agricultural land, and impervious surfaces to assess land cover at the watershed and buffer zone levels. Watershed area was further calculated to analyze whether drainage basin size affected in-stream conditions.

When evaluating the effects of time, riparian characteristics, and land cover on water quality, the only single variable that was found with confidence to predict macroinvertebrate index scores was a lower amount of in-stream woody debris. For the seven sites analyzed, our results surprisingly indicate that a negative relationship exists between woody debris presence and water quality. We attributed this relationship to random chance in a small sample size due to the well-known assertion that the presence of woody debris fosters a beneficial environment for aquatic organisms.

To further examine possible relationships, combinations of variables and their predictive powers were analyzed through multiple variable linear regression tests. Within the context of this study, woody debris and the average DBH of woody stems at each sampled site were present in all significantly predictive regressions. Though woody debris may not be an accurate predictor of water quality within this study, the positive relationship between average DBH and water quality is consistent with our expectations; a greater average DBH suggests a greater tree crown width, and thus a greater potential for habitat, shade, and allochthonous deposits. Time was also a consistent predictor of all three indices when combined with riparian characteristics. This was again expected because increased time strengthens the restorative properties of riparian buffer zones through vegetation growth. Time, however, was not included as a significant predictor when combined with riparian characteristics and land cover. Rather the HBI and H indices could both be predicted by percent impervious surfaces in corresponding watersheds; this negative relationship is indicative of the detrimental effects of impervious surfaces on stream health and is therefore unsurprising.

GIS-analyzed buffer land cover was not significantly related to macroinvertebrate index scores alone or combined with time and riparian characteristics. This lack in relatedness may be due to, again, the small sample size of CREP farms or the computerized estimation of riparian buffer size. If the actual buffers of the sampled streams were smaller or larger than what was generated in ArcGIS, the estimation of land cover within these zones may also be inaccurate, leading to false analysis.

Though many of our predictions were verified in this study, it should again be noted that the sample size was small, with only seven sites used to assess relationships. This small sample size may have contributed to overfitting in the regression analyses; because the number of farms (7) was similar in size to the number of variables tested (8 or 9 independent variables depending on the regression), the R^2 and adjusted R^2 values were extremely high. If this study was extrapolated to include a more representative number of farms in the Shenandoah Valley, the results may be more variable or consistent. However, this analysis can be used as a rudimentary basis of restoration predictive power on water quality if future studies are to be done.

Furthermore, a more comprehensive assessment of riparian zone composition could benefit the rigor of this analysis. Though CREP restoration initiates the removal of cattle from riparian areas, we noted a large number of farms with cattle close to on-site streams. Taking record of grazing animal locations, in addition to other characteristics of farmland outside of the riparian zone, would allow for the inclusion of supplemental variables shown to affect waterway health. Sampling macroinvertebrates at multiple locations within each site would also serve as a more representative indication of overall stream health, as each stream possesses many microhabitats utilized by different organisms.

Simply based on the seven sampled sites, it is suggested that landowners not only consider time, the composition of their riparian zones, or the surrounding land use on restoration effects. Rather, accounting for the interactions and compounding nature of these variables on the health of their stream may be a more beneficial approach. The contiguous nature of groundwater, stream, and surface flow prevents the effectiveness of limited-area restoration and therefore, a more widespread and comprehensive suite of landscape and vegetative factors are necessary to truly repair degraded alluvial networks.

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