

Effects of Cattle Exclusion on Stream Habitat in the Shenandoah Valley, Virginia

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ABSTRACT

Cattle exclusion from streams is believed to improve riparian vegetation, in-stream habitat, and composition of aquatic organisms. Yet research on the effects of cattle exclusion have yielded conflicting results. The goal of this study was to examine relationships between physical habitat and benthic macroinvertebrate populations with increasing downstream distance from cattle-impacted stream segments, and determine which physical habitat and chemical water quality parameters are affected by cattle presence. Macroinvertebrates from 24 sites in Rockingham County, VA were used to calculate bioassessment metrics. Fourteen sites made up 4 longitudinal studies where improvement of biotic condition with distance from cattle impact was examined. Linear regression and multilevel modeling results indicated improving macroinvertebrate assemblage with increasing distance downstream from cattle-impacted reaches. Presence of riparian trees and distance from impact had a positive influence on bioassessment scores. A total of 39 stream sites in the Shenandoah Valley were classified using the Rapid Habitat Assessment (RHA) which is based on 10 visual evaluations of physical characteristics. Four of the ten RHA parameters, embeddedness, bank stability, vegetative protection, and riparian vegetative zone width, along with the total RHA score, were associated with cattle presence. This study found that a) RHA factors reflect direct cattle impacts on the riparian zone, but RHA has limitations as a general predictor of cattle impact, b) cattle influence on benthic macroinvertebrates extends hundreds of meters beyond the immediate pasture boundary, and c) improvement in Virginia Stream Condition Index can be predicted as a function of distance downstream.

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Introduction

The Shenandoah River Valley in Virginia is a primary area of concern in the Chesapeake Bay watershed. Dairy and beef cattle operations are a major source of income in this area, and such intensive cattle agriculture can negatively impact water quality if proper management procedures are not implemented (Krueger et al., 2002; Zeckoski et al., 2007). Impairments due to agricultural operations contribute to more than 36 percent of streams in the southeastern United States not fully supporting their designated uses and thus being classified as impaired due to agricultural pollutants such as pathogens, siltation, habitat alteration, organic enrichments, and nutrients (USEPA, 2000; Agouridis et al., 2005).

Biological assessment studies that examine freshwater organisms such as benthic macroinvertebrates as indicators of water quality are useful because these organisms integrate physical, chemical, and biological impacts on stream communities over time (Stone et al., 2005). Standard chemical monitoring assessments are limited because they only represent the chemical conditions at the exact time when a sample is collected. It is typically expected that macroinvertebrate populations will improve with cattle exclusion because their health can be influenced by degradation of water quality and physical habitat resulting from cattle grazing (Braccia and Voshell, 2007). However, this expected result has not always been supported by studies. For example, Ranganath et al. (2009) found that short segments of stream with cattle exclusion did not result in a positive response in benthic macroinvertebrate populations. On the other hand, Braccia and Voshell (2007) found that macroinvertebrate assemblage was highly correlated with number of cattle per hectare.

While macroinvertebrate assemblage is commonly used to assess water quality due to cattle exclusion in agriculturally impacted streams, there are many confounding factors that

influence the recovery of macroinvertebrate assemblage after cattle exclusion practices are implemented. Such variables, including time since exclusion, length of exclusion, and upstream impacts, have made it difficult to understand the relationship between cattle impacts and macroinvertebrate assemblage. It is important to be able to define the necessary length of cattle exclusion for improving biotic integrity of streams. Thus a longitudinal study examining habitat conditions at different distances downstream from cattle impacts could give valuable information for future agricultural management. Also, macroinvertebrate studies require many samples and a great deal of time to perform. Thus, it is important to evaluate different measures of water and habitat quality to determine whether macroinvertebrate assemblage is a good measure of stream recovery and what other measures may adequately characterize cattle impacts on streams and take less time to perform.

The objectives of this study were:

1. Determine the improvement of physical habitat conditions and benthic macroinvertebrate populations with increasing downstream distance from cattle-impacted stream segments.
2. Determine which Rapid Habitat Assessment parameters are most affected by cattle impacts.
3. Evaluate the relationship between biomonitoring scores and other common metrics for characterizing cattle impacts on stream quality (metrics to be considered include: Rapid Habitat Assessment (RHA), *E. coli*, TSS, turbidity, nutrients, Stream Condition Index (SCI), and EPT).

We predict that:

1. In reaches where cattle are excluded from the stream there will be increasing improvements in benthic macroinvertebrate assemblage with distance from impact; physical habitat quality will not improve with increasing distance from cattle impact.
2. Some parameters within the total RHA evaluation will be more useful for the examination of cattle-impacted streams in the Shenandoah Valley than other parameters.
3. Correlations will exist between biomonitoring results and other physical and chemical water quality parameters, which can be used to more easily assess the impact of cattle on streams.

Literature Review

Cattle Impacts on Stream Water Quality and Physical Habitat

Without proper management, cattle can degrade the chemical, biological, and physical condition of streams and riparian zones. Deposition of urine and manure is one way cattle directly impact streams (Krueger et al., 2002). Such direct depositions contribute to increased dissolved nutrients and increased fecal bacteria concentrations (Zeckoski et al., 2007). Cattle also directly increase sediment by physically trampling in streams (Krueger et al., 2002). However, most water quality degradation that occurs because of grazing is nonpoint source pollution, meaning that deposition of pollutants occurs indirectly over a wide area and is associated with land-use activities and precipitation events (Krueger et al., 2002).

In addition to directly depositing nutrients in and around streams, cattle also increase nitrogen and phosphorous concentrations by decreasing nutrient uptake through plants in the riparian zone, by mobilizing sediment attached nitrogen and phosphorous as a result of disturbing stream bed and banks, and by compacting soil, which increases overland flow during precipitation events (Platts and Nelson, 1985; Platts and Rhinne, 1985; Armour et al., 1991; Sheffield et al., 1997; Quinn et al., 1997). Increases in concentration of nitrogen and phosphorous can cause increases in algal biomass and eutrophication (Quinn et al., 1997). Decreased dissolved oxygen from eutrophication is a major factor impacting the composition of aquatic organism communities such as benthic macroinvertebrates (Connolly et al., 2007). Agriculture is the single largest contributor of nitrogen and phosphorous to the Chesapeake Bay, and models have indicated that reductions in nutrient inputs will result in improvements in bay water quality (Boesch et al., 2001). Since significant reductions in total nitrogen and total phosphorous can result from off-stream watering and cattle exclusion (78.5 and 75.6%

respectively observed by Line et al., 2000), we expect that cattle exclusion practices implemented in small watersheds within the Chesapeake Bay watershed have potential to reduce the nutrient loads to impact the bay.

In addition to chemical pollution, cattle can degrade physical stream habitat and water quality by trampling in the riparian zone, which contributes to increased soil compaction, decreased infiltration, increased stream bank erosion, increased suspended solids, increased embeddedness, widening of channels, loss of shade from riparian vegetation, and increased water temperatures (Herbst and Kane, 2009; Scrimgeour and Kendall, 2003). When soil becomes mobile due to erosion, fine sediments clog the interstitial pores of stream-bed material and degrade the habitat available to fish, aquatic macroinvertebrates, and periphyton (Sylte and Fischenich, 2002). Also, such stream-bank erosion increases turbidity and total suspended solids (TSS), but cattle exclusion management practices have been successful at reducing TSS loads (Line et al., 2000). It has been suggested that erosion of streambanks is the dominant cattle resultant impact that can be alleviated by cattle exclusion; Scrimgeour and Kendall (2002) found that stable streambanks increased by 50% due to 2 years of cattle exclusion. The main reasons for such increases in stream-bank stability are resultant re-growth of vegetation along banks and in stream channels and the development of root systems that stabilize potentially erodible soil (Scrimgeour and Kendall, 2002).

The US Environmental Protection Agency (EPA) has developed a method for assessing streams called the Rapid Habitat Assessment (RHA), which examines ten physical parameters of stream condition for high and low gradient streams. The parameters examined by the high gradient assessment include: epifaunal substrate and available cover, embeddedness, velocity and depth regime, sediment deposition, channel flow status, channel alteration, frequency of riffles,

bank stability, bank vegetative protection, and riparian vegetation zone width (Barbour et al., 1999). Some of these parameters likely to be affected by cattle are available cover, embeddedness, bank stability, vegetative protection, and riparian vegetation. Usually biological assessments center on the assumption that organism communities are determined by the physical habitat, and thus the condition of the habitat is implied by the resultant biological indices (Maddock, 1999). However, while biological assessments of stream condition are valuable, the biotic integrity of a stream can be influenced by physical habitat quality, chemical water quality, biological factors such as predation and competition, or combinations of these; thus it is essential to perform a physical habitat assessment of streams to understand stream health (Maddock, 1999). Based on several sets of data, the Virginia Department of Environmental Quality (VDEQ) has determined that RHA scores for the Ridge and Valley region of Virginia are typically between 120 and 140, with 120 indicating poor habitat conditions and 140 indicating good habitat conditions (VDEQ, 2006).

Macroinvertebrate assemblage (measured with Hilsenhoff Biotic Index-HBI) was highly correlated with stream physical habitat (RHA) scores in agriculturally impacted streams in Illinois (Stone et al., 2005). Ranganath et al. (2009) compared RHA scores between grazed and cattle exclusion reaches of streams and found that there was a statistical difference between the scores, with greater scores where cattle were excluded. Also, an additional study done in Virginia found that measures of physical habitat such as percent fines and substrate were highly correlated with macroinvertebrate assemblage in streams with a gradient of cattle grazing impacts (Braccia and Voshell, 2006b).

Importance of Riparian Buffers

Riparian corridors are the areas along the edges of streams that typically contain more vegetation biomass and have a considerable impact on the dynamics of the stream. They are an ecotone between streams and their surrounding watersheds, and locations where two ecosystems connect are environmentally important because there is often greater biodiversity (Minstrall, 1988). There are over 15.8 million hectares of pasture and grazed forest and almost one million kilometers of streams in the southern humid region of the United States, which creates a high potential for degradation of streams due to grazing impacts (Aguoridis et al., 2005). When agricultural settlements arose along streams, farmers typically removed the vegetation along streams and altered their flow paths to allow for more cattle and crop production (Aguoridis et al., 2005). Unfortunately such practices removed the main energy source (autumnal leaf fall) and the filtering system for pollutants entering the stream.

Riparian zones play a very important role in stream processes. Vegetated riparian zones reduce peak flood impacts because they increase channel roughness which slows down the flood wave (Aguoridis et al., 2005). By reducing the velocity of runoff and increasing the sinuosity of flow paths, riparian buffers induce settling of sediments and large organic particles, infiltration of runoff, and nutrient uptake (Aguoridis et al., 2005). The filtering and settling of pollutants in headwater riparian zones is critical because these small waterways contribute to larger water bodies downstream like the Chesapeake Bay (Likens, 1985). Riparian zones also greatly impact the energy resources of streams by influencing the light availability and detritus inputs (Hughes, 2008). Finally, buffer zones control water temperatures with shade, which makes the in-stream habitat more suitable for diverse communities of plants, algae, fish, and macroinvertebrates (Aguoridis et al., 2005). Line *et al.* (2000) found that cattle exclusion resulted in the re-establishment of riparian buffer zones and the reduction of sediment and nutrient levels. When

cattle are excluded from streams, streambanks are stabilized and riparian vegetation improves which increases the quality of habitat for aquatic organisms and wildlife in and adjacent to the stream (Zeckoski et al., 2007).

Cattle Impacts on Benthic Macroinvertebrates

Benthic macroinvertebrates are a group of freshwater aquatic organisms, including insects, snails, and crayfish, which are highly adapted to a range of environmental conditions (Braccia and Voshell, 2006a). Biological assessment studies that use freshwater organisms such as benthic macroinvertebrates as indicators of water quality conditions have become increasingly common because these organisms reflect physical, chemical, and biological impacts on streams, while standard chemical monitoring assessments are limited (Stone et al., 2005). Monitoring of organisms is valuable because they are directly related to ecosystem integrity and function; they also integrate conditions over time and space, whereas traditional chemical sampling only gives a snapshot of the environmental conditions (Heatherly et al., 2007). Studying benthic macroinvertebrate populations is a valuable way of assessing the success of stream restoration goals because they are sensitive indicators of stream habitat structure in response to improved physical habitat conditions, and they have been commonly used in stream monitoring (Herbst and Kane, 2009).

While benthic macroinvertebrate assemblage is negatively affected by poor habitat conditions such as decreased substratum size and stability, these organisms also respond to water chemistry conditions like decreased dissolved organic matter, low dissolved oxygen, and increases in nutrient concentrations (Heatherly et al., 2007). Cattle grazing can induce changes in the environment that degrade habitat quality in and around streams, degrade water quality, and alter many physical and chemical habitat characteristics that influence macroinvertebrate health

(Braccia and Voshell, 2007). Thus, examining macroinvertebrate assemblage is a good assessment tool for understanding the success of water quality management practices such as cattle exclusion.

It is well understood that macroinvertebrates respond to land use practices, and there is much information available about tolerance of specific taxa to disturbances and pollution (Stone et al., 2005). Taxa such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) are less tolerant of pollution and physical changes in their environment, and they will be some of the first to respond to anthropogenic degradation (Lenat and Resh, 2001; Braccia and Voshell, 2006a). The results of an experiment in Illinois streams indicated that differences in macroinvertebrate assemblage were associated with physical habitat degradation and high nutrient concentrations (Heatherly et al., 2007). Also, Stone et al. (2005) found that among relationships between riparian land cover, in-stream habitat, water chemistry, and macroinvertebrates, that macroinvertebrates were most highly correlated with in-stream habitat scores and riparian cover. They also concluded that percent insect density was correlated with riparian cover and was thus a good metric to assess agricultural streams (Stone et al., 2005). These studies however, did not attempt to examine the specific responses of macroinvertebrates to cattle impacts.

In a two year study done in Alberta, Canada, where stream reaches were subjected to different degrees of cattle grazing, Scrimgeour and Kendall (2003) found that treatments did *not* cause changes in benthic macroinvertebrates, but the exclusion of cattle did increase bank stability, riparian vegetation biomass, in-stream biomass, and benthic coarse particulate organic matter. In a study done in southwest Virginia, comparing un-grazed and grazed streams, Ranganath et al. (2009) found differences in stream morphology and riparian vegetation between the two treatments, but benthic macroinvertebrate assemblage was not significantly different.

They concluded that short reaches of cattle exclusion were insufficient for improving macroinvertebrate assemblage, but a full watershed approach may improve biotic integrity of streams (Ranganath et al., 2009).

While these studies have not found differences in macroinvertebrate assemblage as a result of cattle exclusion, Braccia and Voshell (2007), in a study in the Blue Ridge Mountains of Virginia, found a strong linear correlation between macroinvertebrate assemblage and cattle grazing intensity (cattle ha⁻¹). They also identified sedimentation as the main stressor on benthic macroinvertebrates due to cattle impacts in small headwater streams (Braccia and Voshell, 2006b). In this study there was little to no upstream disturbance, which likely contributed to the strong relationship they found between macroinvertebrates and cattle per hectare (Braccia and Voshell, 2007). In another study in Virginia, Hughes (2008) found that, while shredder macroinvertebrates increased due to cattle exclusion, complete ecosystem recovery in response to cattle exclusion may take more than 15 years. It is clear that physical habitat degradations such as erosion and sedimentation negatively affect macroinvertebrates (Stone et al., 2005; Braccia and Voshell, 2006b; Heatherly et al., 2007). Also it is clear that cattle exclusion results in physical habitat improvements such as stream-bank stabilization and re-growth of riparian vegetation (Scrimgeour and Kendall, 2002; Ranganath et al., 2009). However, there have been conflicting results in previous studies examining the direct relationship between macroinvertebrate assemblage and cattle exclusion practices (Scrimgeour and Kendall, 2003; Braccia and Voshell, 2007; Ranganath et al., 2009).

Macroinvertebrate Assessment Indices

There are many ways of assessing benthic macroinvertebrate health. In general, the total number of taxa decreases and the populations of macroinvertebrates become more homogeneous

in response to degradations due to impacts such as cattle (Braccia and Voshell, 2007). Thus, some studies have examined the biodiversity of the macroinvertebrates by calculating different diversity metrics, such as species richness, Shannon's diversity, evenness, and Simpson's diversity (Heatherly et al., 2007). Also, there are certain groups that are indicators of water-quality conditions. For example, Chironomidae are tolerant of pollution and indicate low dissolved oxygen and Oligochaeta are also tolerant of pollution, while Ephemeroptera, Plecoptera, and Trichoptera (EPT) are indicators of good water quality because they are generally intolerant to pollution (Braccia and Voshell, 2007). Sensitive taxa are commonly replaced by tolerant taxa such as Chironomidae in cattle-impacted streams (Braccia and Voshell, 2007). Because of this, many studies look at the percentage or richness of these groups in their samples as a way of assessing macroinvertebrate assemblage (Heatherly et al., 2007; Ranganath et al., 2009; Scrimgeour and Kendall, 2003).

In addition to examining biodiversity and the presence of certain taxa as indicators of benthic macroinvertebrate health, some studies have also looked at percentages of functional feeding groups in the macroinvertebrate communities such as: % grazer, % gatherer, % filterer, % shedder, and % scraper for each sample (Heatherly et al., 2007). Due to riparian zone changes in response to cattle grazing, algae grazers and fine detritus filterer taxa are dominant in cattle-impacted streams whereas shredders are less abundant (Braccia and Voshell, 2007). Stone *et al.* (2005) found that the % insects relative to all the macroinvertebrates in the sample was correlated with percent fines and was thus a good indicator of sedimentation caused by cattle grazing. Information about the assemblage of macroinvertebrates tells researchers about what they are eating and the environment they live in, and thus gives insight to environmental conditions upstream from the sampling location and in the riparian zone.

The Virginia Stream Condition Index (VASCI) is a multi-metric score for a stream site based on the assemblage of benthic macroinvertebrates in the sample (Burton and Gerritsen, 2003; Heatherly et al., 2007; Ranganath et al., 2009). The VASCI is composed of eight metrics including: taxa richness, EPT index, percent Ephemeroptera, percent Plecoptera and Trichoptera minus Hydrophychidae, percent scrapers, percent Chironomidae, percent dominant taxon, and the Modified Family Biotic Index (MFBI) (Burton and Gerritson, 2003). The Stream Condition Index quantifies results from the functional feeding groups present, the different indicator groups, diversity metrics, and macroinvertebrate pollution tolerance values to give a total representative assessment of macroinvertebrate health (Burton and Gerritsen, 2003). The score ranges from 0 to 100, with scores below 60 indicating impaired streams (Burton and Gerritsen, 2003).

Methods

Site Description

All study sites were located in the Shenandoah Valley, in Rockingham County, Virginia. The average yearly precipitation in Harrisonburg, which is the main city in Rockingham County, is 920 mm, the warmest month of the year is usually July with an average maximum temperature of 30 °C, and the coldest month of the year is usually January with an average minimum temperature of -6.4 °C (IDcide, 2011).

Macroinvertebrates were collected at 24 locations. Thirteen of these sites made up longitudinal studies along four stream reaches. The other 11 sites represented a range of stream and landuse conditions to examine water quality relationships.

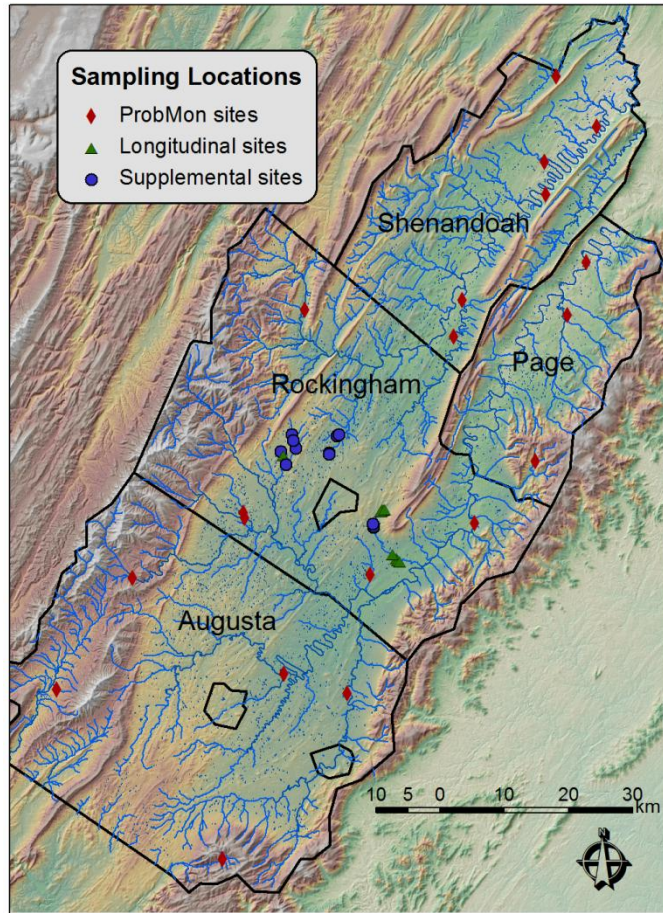


Figure 1: Locations where samples were collected throughout the Shenandoah Valley, including longitudinal study sites, supplemental sites, and ProbMon sites.

Site characteristics including flow rate (m^3/s) (measured on the day of benthic sampling), geology, stream order, total watershed area (km^2), and percent pasture in the watershed were determined (Table 1). The geology of most sites is limestone and dolomite, with some shale and black shale (USGS, 2010). Discharge was determined using a Marsh-McBirney flow meter to measure velocity for eight to ten segments perpendicular to the thalweg. Depth and segment width were used to determine flow area, and with velocity (m/s) combined to determine discharge (m^3/s). Stream order, total watershed area, percent watershed in pasture, and distance from cattle impacts were determined using ArcGIS and the National Hydrography Dataset (NHD)(USDA, 2011), National Elevation Data (NED) (USDA, 2000), and National Land Cover Dataset (NLCD)(USDA, 2001).

Table 1: Site characteristics for macroinvertebrate sites.

Site ID	Flow Rate ¹ (m ³ /s)	Geology ²	Stream Order ³	WS Area ⁴ (km ²)	% WS in pasture	Dist from cattle impact (m)
CR1a	0.044	Dolomite/ Limestone	3	13.22	14.0	0
CR2	0.018	Dolomite/ Limestone	3	13.37	14.9	238
CR3	0.018	Dolomite/ Limestone	3	13.95	16.1	668
CR4	0.031	Dolomite/ Limestone	3	13.98	16.2	814
CR6	0.016	Dolomite/ Limestone	3	49.05	37.7	0
CR7	0.028	Dolomite/ Limestone	3	50.46	38.8	354
CR8	0.019	Dolomite/ Limestone	3	50.64	38.9	677
CR9	0.018	Limestone/Dolomite	3	51.05	39.2	1189
LN4a	0.005	Limestone/Black Shale	3	6.99	64.7	-
LN4	0.020	Limestone/Black Shale	3	11.59	68.3	-
LW5	0.065	Shale/ Sandstone	3	17.43	59.5	-
LW6	0.090	Shale/ Sandstone	3	17.57	59.8	-
MC1	0.022	Limestone/Dolomite	2	4.20	49.1	-
MC2	0.023	Limestone/Dolomite	4	8.71	55.4	-
MCG	0.026	Dolomite/ Limestone	4	37.04	59.5	-
MV1	0.018	Dolomite/ Limestone	1	2.41	55.9	5
MV2	0.016	Dolomite/ Limestone	1	2.48	56.4	337
SL1	0.023	Limestone/Dolomite	3	7.30	57.1	0
SL2	0.040	Limestone/Dolomite	3	8.91	58.6	304
SL3a	0.028	Dolomite/ Limestone	3	9.94	61.9	1604
SN2	0.014	Dolomite/ Limestone	2	4.73	69.0	-
TF3	0.028	Dolomite/ Limestone	2	3.77	68.5	-
TFN	0.058	Dolomite/ Limestone	2	4.06	69.8	-
TFW	0.006	Dolomite/ Limestone	1	1.46	57.7	-

1. Flow rate was measured once on the day of benthic sampling.
2. Geology determined from State geologic map (USGS, 2010).
3. Strahler stream order based on blue-line streams from 1:24,000 USGS 7.5 minute topographic maps.
4. Watershed (WS) area as defined from GIS elevation data (USDA, 2000).
5. Slope of stream reach at sample location
6. Area in pasture as defined in the National Land Cover Dataset (USDA, 2001).
7. Distance to nearest upstream point of cattle impact.

Longitudinal Study Design

To examine objective 1 and determine the improvement of physical habitat conditions and benthic macroinvertebrate populations with increasing downstream distance from cattle-impacted stream segments, four longitudinal stream segments were studied. The distances of

each longitudinal sampling point downstream from the cattle impacts were determined (Table 1). Three replicate benthic macroinvertebrate samples were taken at each site to examine the biological condition of the location, and RHA was used to examine the physical habitat condition.

The CRa longitudinal study was along Cub Run from CR1-CR4 (Figure 2). There was recent cattle impact directly above CR1a, which began in November of 2010. From CR1a to CR2, the stream had CREP (Conservation Reserve Enhancement Program) fencing implemented in 2009. Between CR2 and CR4, top of bank fencing had excluded cattle since 2009 except for occasional short-term grazing (usually less than a week per occurrence) during hot weather.

The MV longitudinal segment was along Mountain Valley Tributary, which enters Cub Run directly above CR4 (Figure 2). Points MV1 and MV2 were examined in this longitudinal study. Top of bank fencing was implemented along Mountain Valley Tributary in 2009. There were significant cattle impacts directly upstream (across the road) from MV1.



Figure 2: Longitudinal Study CRa and MV along Cub Run and Mountain Valley Tributary respectively in Rockingham County, VA. Macroinvertebrate samples were collected at CR1a, CR2, CR3, CR4, MV1, and MV2. Cattle were excluded between CR1a and CR4 and MV1 and MV2. There have been cattle present upstream of CR1a since November 2010. There has been long-term significant cattle presence upstream of MV1.

Longitudinal study CRb was farther downstream on Cub Run at sites CR6-CR9 (Figure 3). There was cattle access to the stream above and below CR6, but 537 m below CR6 stream exclusion fencing began and continued to CR9. This fencing has been in place for eight years.

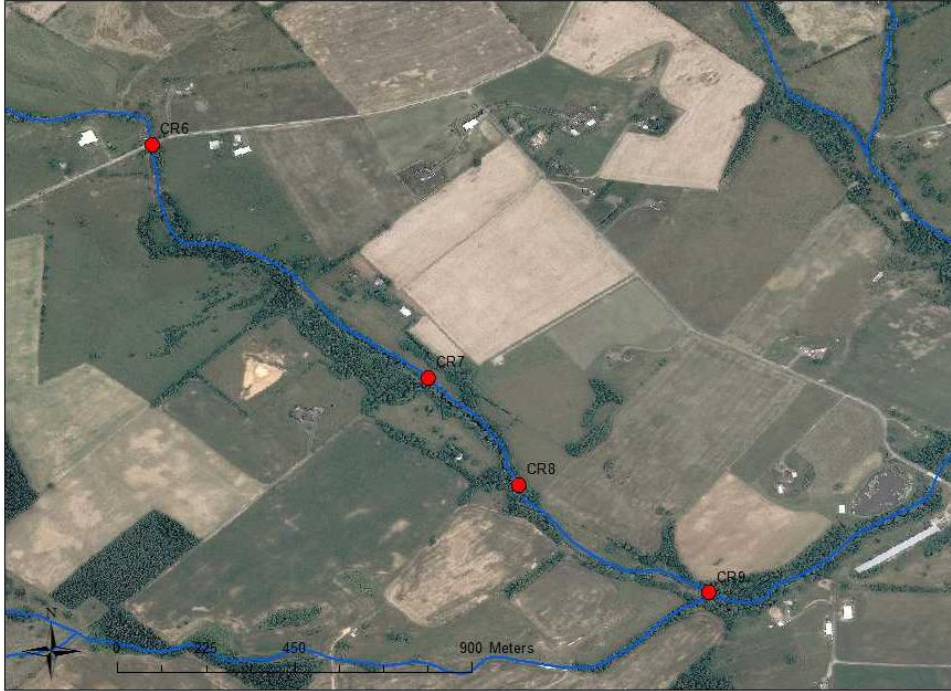


Figure 3: Longitudinal Study CRb along Cub Run in Rockingham County, VA. Macroinvertebrate samples were collected at CR6, CR7, CR8, and CR9. Cattle had access to the stream at CR6 and were excluded from about 537 m below CR6 to CR9.

Longitudinal study SL was along Silver Creek from sites SL1-SL3a (Figure 4). There were cattle impacts starting at SL1 through 400 m below that point. Cattle had been excluded from ~300 m above SL2 downstream until SL3a. Fencing had been in place since 2003.

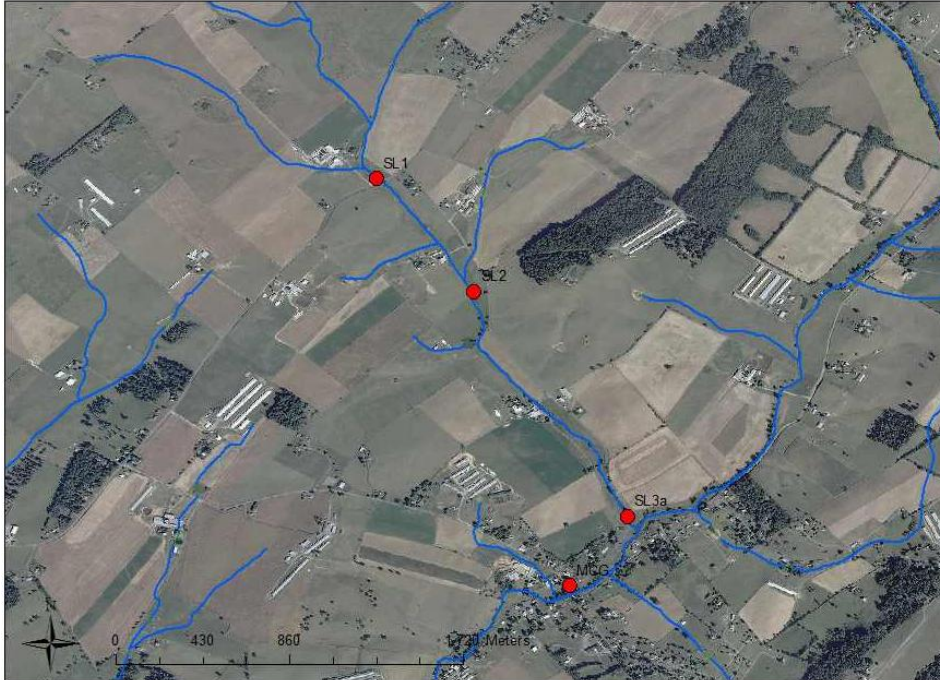


Figure 4: Longitudinal Study SL along Silver Creek in Rockingham County, VA. Macroinvertebrate samples were collected from SL1, SL2, and SL3a. Cattle had access to the upper segment of the stream and were excluded from about 300 m upstream of SL2 to SL3a.

Benthic Sampling

Benthic macroinvertebrate samples were taken in June of 2011. At each site, three samples were collected in riffles. Samples were spaced approximately 2 m apart within the riffle. Also, samples were taken at varying distances across the stream to allow for more habitat and substrate types to be sampled.

Benthic samples were collected by inserting a Surber sampler (0.093 m^2) into the stream bed material. Within the sampler, macroinvertebrates, organic detritus, and inorganic substrates were disturbed and scrubbed by hand in such a way that all dislodged material would wash into the Surber net downstream. Material collected in the Surber net was transferred into a bucket. The net was rinsed thoroughly so that all macroinvertebrates were transferred. The bucket contents were poured through a $500 \text{ }\mu\text{m}$ sieve to remove excess water. All sieve contents were

rinsed into 1 L sample containers for storage. They were preserved with 91% isopropyl alcohol and transported back to the laboratory to be analyzed.

In the lab, samples were rinsed into the sieve again to remove the majority of the alcohol. Sample contents were transferred into a dissecting pan. Using a light to aid visualization (and a magnifying glass as needed) all macroinvertebrates were hand sorted from organic detritus and inorganic material and removed with forceps. Entire benthic samples were sorted; no subsampling was done. Macroinvertebrates were again preserved in containers with 95% ethanol. Next, all macroinvertebrates were counted and identified using a dissecting microscope with 1X and 2X magnification. Organisms were identified using *A Guide to Common Freshwater Invertebrates of North America*, by J. Reese Voshell (2002).

Stream Physical Habitat Quality

Habitat quality was determined for the visible reach upstream of each sample site listed in Table 1 and 18 additional sites throughout Rockingham and Augusta Counties using the U.S. Environmental Protection Agency's RHA for high gradient streams (Barbour et al., 1999). All streams examined were headwater streams so the high gradient assessment was used. Based on this protocol, streams were assigned a score between 0 and 20 based on visual assessment for features including epifaunal substrate/available cover, embeddedness, velocity/depth regimes, sediment deposition, channel flow status, channel alteration, frequency of riffles or bends, bank stability, vegetative protection, and riparian vegetative zone width (Barbour et al., 1999). These parameter scores were added to get a total RHA score, which ranges between 0 and 200 (VDEQ, 2006). In this region of Virginia, scores below 120 indicate impaired conditions (VDEQ, 2006).

Stream Chemical Water Quality

Weekly grab samples were taken from most study sites from May through August of 2011. These weekly samples were not collected at the CR4, CR6, CR7, CR8, and CR9 sites. Only one grab sample was taken at these sites the week of macroinvertebrate sampling (June 2011). Weekly grab samples were taken the same day every week from the thalweg of the stream. As samples were collected, care was taken to not disturb fine bed material. Measurements of pH, conductivity, and turbidity were made on site. Water samples were transported on ice to Virginia Tech for analysis of total suspended solids (TSS), *E. coli*, total nitrogen and total phosphorous.

Data Analysis

Each macroinvertebrate group was assigned a pollution tolerance value, a functional feeding group, and a mode of existence (how the organism moves or stays in one location in the stream) (Burton and Gerritsen, 2003). Functional feeding group and tolerance values were assigned based on the Virginia Stream Condition Index (VASCI) guidelines (Burton and Gerritsen, 2003). Pollution tolerance values vary from 0 to 10, with 0 indicating very sensitive and 10 indicating very tolerant to pollution (Burton and Gerritsen, 2003). These values and the numbers of each type of macroinvertebrate found were used to calculate macroinvertebrate metrics for each site. Metrics included: VASCI, EPT, richness, % Chironomidae, %EPT, %EPT less Hydropsychidae (%EPT-H), % scraper, % filterer, % shredder, and % insects.

Longitudinal Studies

Individual linear regression models were created for each of the longitudinal study sites to explain the behavior of each macroinvertebrate index and RHA with increasing distance away from cattle impact. Models were created using both distance and presence/absence of trees as

predictor variables in the macroinvertebrate models. The linear regression models were fit for each longitudinal site and for each parameter. For some of the longitudinal studies, the homoscedasticity assumption was not met. In such cases, a weighted least squares test was done based on the squared residuals from the regular regression. The advantage of using this type of test in cases where variances are unequal is that tighter data is weighted higher in the model.

In addition to having an individual model for each longitudinal site, the macroinvertebrate data from all longitudinal sites were also joined together based on distance from cattle impacts. Using this lumped data, a multilevel model was built. Multilevel modeling gave an idea about the overall influence of the x-variables taking into account the variability associated with the different longitudinal studies; it accounts for random effects. Based on this sort of model, assumptions can be made about the population of streams rather than just the individual streams that were examined using the individual models.

Rapid Habitat Assessment

Rapid Habitat Assessment (RHA) scores were grouped based on the presence, absence, or intermittent presence of cattle in order to understand which parameters would differ based on cattle impacts. The normality of data for each parameter was determined based on examination of the normal quantile plot. For normal data, ANOVA tests were performed for each RHA parameter to determine whether a difference existed between the groups (cattle present, intermittent, and cattle absent). For the parameters that had non-normal data, Kruskal Wallis tests were done to determine whether differences existed between the groups. When differences were present, Tukey's HSD multiple comparison method was used to determine which groups differed. For all statistical analyses, an α value of 0.10 was used.

Water Quality Metric Evaluation

Median values for TSS, turbidity, conductivity, *E. coli* MPN, total nitrogen, and total phosphorous (from the weekly grab samples taken during the spring and summer of 2011) were compiled for macroinvertebrate and RHA sites. The correlation between all water quality parameters (VASCI, EPT, RHA, TSS, turbidity, conductivity, *E. coli* MPN, total N, and total P) was determined in order to examine which parameters were correlated with macroinvertebrate parameters.

The Probabilistic Monitoring (ProbMon) program is a Virginia Department of Environmental Quality (VDEQ) monitoring program that selected random locations throughout the state to monitor chemical, physical, and biological stream water quality (VDEQ, 2012). The same water quality parameters we had from our sites were accessed for the ProbMon locations in the Shenandoah Valley, including Augusta, Page, Rockingham, and Shenandoah Counties (Figure 1) (VDEQ, 2011). Site characteristics, including stream order, total watershed area (km²), mean percent slope, and percentage of watershed in pasture for each of the ProbMon locations, were determined from the ProbMon database (Table 2). The correlation between VASCI, EPT, and various other water quality parameters was determined from the selected ProbMon data. These correlations were used as a reference for comparison with the stream data from this study. Finally, both data sets were combined and the correlation between parameters was assessed.

Table 2: ProbMon site characteristics including: county, stream order, total watershed area, mean percent slope, and percentage of watershed that is pasture. Data is from VDEQ ProbMon Database (VDEQ, 2011).

Site Name	County in VA	Stream Order	Total Watershed Area (km²)	Mean Slope (%)	% Watershed in Pasture
1BNTH046.56	Augusta	2	53.73	0.826	0.0
2-SMR004.80	Augusta	2	9.46	-	0.0
1BMDL026.58	Augusta	3	402.43	-	32.9
2-DDY000.75	Augusta	1	6.04	2.436	0.0
1BSTH013.58	Augusta	4	457.74	0.017	20.1
1BSSF038.45	Page	5	3734.81	-	31.5
1BDRI000.21	Page	1	34.28	-	20.7
1BNKW001.97	Page	2	15.02	-	2.8
1BSSF086.12	Rockingham	5	2924.77	-	33.3
1BBRY001.78	Rockingham	2	87.62	-	5.5
1BBVR000.84	Rockingham	2	33.15	-	30.1
1BNFS102.55	Rockingham	4	178.23	-	7.6
1BMIC001.99	Rockingham	2	29.73	0.430	66.1
1BNFS020.11	Shenandoah	4	1912.47	-	31.5
1BSMT009.08	Shenandoah	3	223.10	0.138	43.0
1BSMT001.53	Shenandoah	3	265.34	0.171	39.7
1BPGH000.29	Shenandoah	1	34.67	-	46.3
1BNFS048.74	Shenandoah	4	1678.70	-	30.6
1BCDR027.54	Shenandoah	3	75.79	0.509	5.5

-Indicates no data was available from the ProbMon database.

Results and Discussion

Longitudinal Studies

Longitudinal Macroinvertebrate Studies

Macroinvertebrate indices, including VASCI, EPT, Richness, % Chironomidae, % EPT, % EPT less Hydropsychidae (% EPT-H), % scraper, % filterer, % shredder, and % insects, were calculated for each site along the four longitudinal study segments, CRa, CRb, MV, and SL (Figures 2-4). Graphs of selected macroinvertebrate indices versus distance from cattle impact are shown in Figures 5-9.

Individual linear regression models for each longitudinal study were created in order to determine whether the trends between the macroinvertebrate indices and distance indicated significant improvement in the stream biological condition. The regression results include models for each site and each macroinvertebrate index versus distance (Table 3). The macroinvertebrate indices were the response variables, while distance away from cattle impact was the predictor variable. Also, multiple linear regression models were created using both distance and riparian tree cover (presence/absence) indicator variables versus the different macroinvertebrate indices (Table 4). Regression models that included the tree cover variable were only created for the CRa and CRb longitudinal studies because no tree cover was present along the MV and SL stream reaches. None of the macroinvertebrate indices were significantly related to distance for all four longitudinal sites. However, there was significant improvement in stream biological condition with increasing distance from cattle impact for many of the longitudinal studies.

VASCI was expected to increase with distance from cattle impacts to indicate improved biological condition. Distance from cattle impact was only a significant explanatory variable for

VASCI in the CRa study, while the relationship was not significant for the CRb, MV, and SL studies (Figure 5; Table 3; lines 1-4). When trees were incorporated into the model, both distance from impact and the tree variable were significant explanatory variables for VASCI along CRa and CRb segments (Table 4; lines 1 and 2). The addition of trees to the regression equation improved the relationship between distance and VASCI. Also, both distance from impact and presence of riparian tree cover increased VASCI scores.

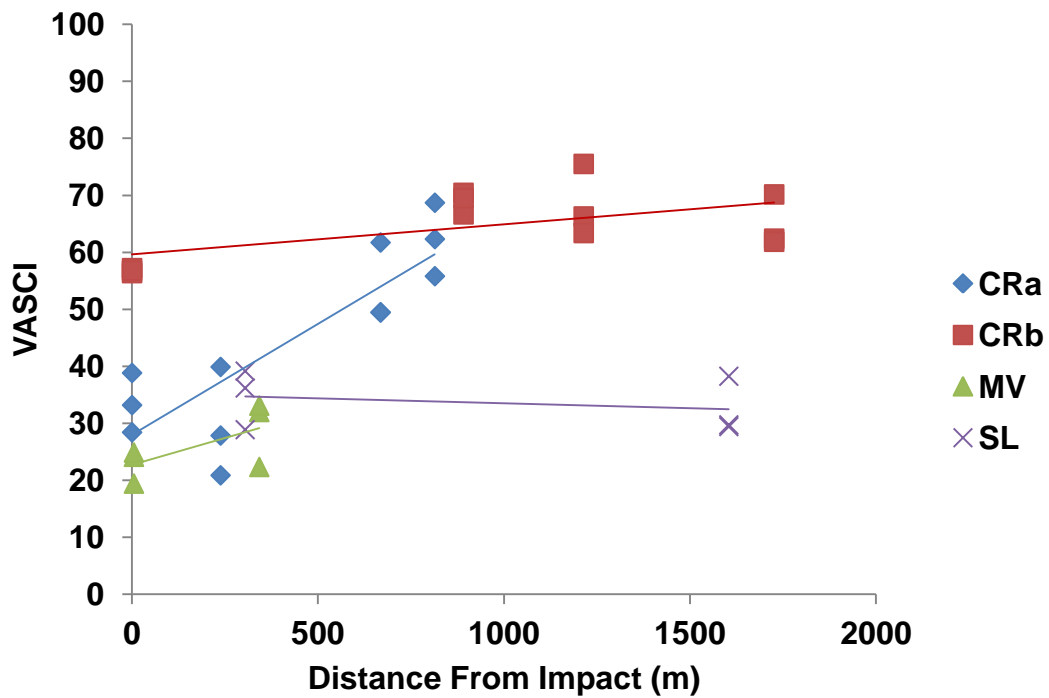


Figure 5: Virginia Stream Condition Index (VASCI) versus downstream distance from cattle impact (m) for four stream reaches.

Table 3: Macroinvertebrate Index Regression Results for distance from impact (D) versus different macroinvertebrate indices.

	Site Name	Macroinvert. Parameter	r ²	P-value: distance	Equation
1	CRa	VASCI	0.73	0.000*	VASCI=28+0.039xD
2	CRb	VASCI	<0.01	0.89	VASCI=67+5.8x10 ⁻⁴ xD
3	MV	VASCI	0.41	0.17	VASCI=23+0.019xD
4	SL	VASCI	0.07	0.62	VASCI=35-1.8x10 ⁻³ xD
5	CRa	EPT	0.34	0.04*	EPT=6.3+3.2x10 ⁻³ xD
6	CRb	EPT	0.26	0.09*	EPT=8.5+7.4x10 ⁻⁴ xD
7	MV	EPT	0.10	0.54	EPT=1.3+3.0x10 ⁻³ xD
8	SL	EPT	0.93	<0.01*	EPT=-0.016+3.7x10 ⁻³ xD
9	CRa	Richness	0.59	<0.01*	S=11+8.9x10 ⁻³ xD
10	CRb	Richness	0.05	0.49	S=23-1.1x10 ⁻³ xD
11	MV	Richness	0.40	0.18	S=11+0.012xD
12	SL	Richness	0.20	0.38	S=11+2.8x10 ⁻³ xD
13	CRa	% Chironomidae	0.83	<0.01*	% C=80-0.062xD
14	CRb	% Chironomidae	0.15	0.21	% C=20-4.9x10 ⁻³ xD
15	MV	% Chironomidae	0.54	0.09*	% C=25+0.095xD
16	SL	% Chironomidae	0.92	<0.01*	% C=10+0.034xD
17	CRa	% EPT	0.81	<0.01*	% EPT=14+0.039xD
18	CRb	% EPT	0.02	0.70	% EPT=57+1.7x10 ⁻³ xD
19	MV	% EPT	0.02	0.77	% EPT=0.11+8.9x10 ⁻³ xD
20	SL	% EPT	0.68	0.04*	% EPT=-0.010+4.5x10 ⁻⁵ xD
21	CRa	% EPT -H	0.60	<0.01*	% EPT-H=14+0.026xD
22	CRb	% EPT -H	0.03	0.61	% EPT-H=37-1.5x10 ⁻³ xD
23	MV	% EPT -H	0.22	0.34	% EPT-H=0.23+1.4x10 ⁻³ xD
24	SL	% EPT -H	0.71	0.04*	% EPT-H=-0.88+4.1x10 ⁻³ xD
25	CRa	% Scraper	0.98	<0.01*	% Scraper=1.4+0.018xD
26	CRb	% Scraper	0.07	0.40	% Scraper=20+3.2x10 ⁻³ xD
27	MV	% Scraper	0.45	0.15	% Scraper=0.93+0.021xD
28	SL	% Scraper	0.19	0.38	% Scraper=2.2+3.2x10 ⁻³ xD
29	CRa	% Filterer	0.33	0.06*	% Filterer=6.0+0.011xD
30	CRb	% Filterer	0.07	0.42	% Filterer=22+2.9x10 ⁻³ xD
31	MV	% Filterer	0.71	0.05*	% Filterer=1.8+0.025xD
32	SL	% Filterer	0.88	0.01*	% Filterer=1.6+6.2x10 ⁻³ xD
33	CRa	% Shredder	0.31	0.06*	% Shredder=-1.3+0.013xD
34	CRb	% Shredder	0.28	0.08*	% Shredder=0.82+9.0x10 ⁻⁴ xD
35	MV	% Shredder	0.56	0.09*	% Shredder=0.72+4.4x10 ⁻³ xD
36	SL	% Shredder	4.9*10 ⁻⁵	0.99	% Shredder=0.33+1.9x10 ⁻⁶ xD
37	CRa	% Insects	0.22	0.12	% Insects=100- 4.1x10 ⁻³ xD
38	CRb	% Insects	0.10	0.33	% Insects= 98-7.4x10 ⁻⁴ xD
39	MV	% Insects	0.64	0.06*	% Insects=30+0.14xD
40	SL	% Insects	0.90	<0.01*	% Insects=29+0.039xD

D= distance from cattle impact (m). Distance p-value determines whether distance is a significant indicator variable for parameters. * indicates significant p-value with $\alpha=0.10$. % EPT-H is the percentage of all EPT taxa minus the Hydropsychidae family out of the total number of macroinvertebrates.

Table 4: Macroinvertebrate Index Regression Results for distance from impact (D) and tree (T) versus different macroinvertebrate indices.

	Site Name	Macroinvert. Parameter	r²	P-value: distance	P-value: tree cover	Equation
1	CRa	VASCI	0.83	0.05*	<0.01*	VASCI=21.5+0.0337xD+11.6xT
2	CRb	VASCI	0.94	0.01*	<0.01*	VASCI=56.9+3.40x10 ⁻³ xD+7.95xT
3	CRa	EPT	0.57	0.11	0.06*	EPT=5.1+2.3x10 ⁻³ xD+2.1xT
4	CRb	EPT	0.28	0.09*	0.57	EPT=8.7+7.8x10 ⁻³ xD-0.32xT
5	CRa	Richness	0.68	0.01*	0.14	S=9.5+7.6x10 ⁻³ xD+2.8xT
6	CRb	Richness	0.85	<0.01*	<0.01*	S=23-1.5x10 ⁻³ xD+2.1xT
7	CRa	% Chironomidae	0.99	<0.01*	<0.01*	% C=89-0.056xD-15xT
8	CRb	% Chironomidae	0.68	0.21	<0.01*	% C=24-2.8x10 ⁻³ xD-9.6xT
9	CRa	% EPT	0.85	<0.01*	0.18	%EPT=11+0.036xD+6.6xT
10	CRb	% EPT	0.14	0.83	0.28	% EPT=54+9.6x10 ⁻⁴ xD+6.1xT
11	CRa	% EPT -H	0.65	0.01*	0.32	% EPT-H=11+0.023xD+5.6xT
12	CRb	% EPT -H	0.70	0.15	<0.01*	% EPT-H=33-2.7x10 ⁻³ xD+9.7xT
13	CRa	% Scraper	0.76	<0.01*	0.31	% Scraper=-1.3+0.018xD+3.2xT
14	CRb	% Scraper	0.17	0.49	0.32	% Scraper=17+2.6x10 ⁻³ xD+4.8xT
15	CRa	% Filterer	0.24	0.09*	0.68	% Filterer= 5.0+10x10 ⁻³ xD+1.7xT
16	CRb	% Filterer	0.16	0.35	0.35	% Filterer= 24+3.5x10 ⁻³ xD-4.3xT
17	CRa	% Shredder	0.27	0.26	0.40	% Shredder=-0.43+3.2x10 ⁻³ xD+1.8xT
18	CRb	% Shredder	0.41	0.09*	0.19	%Shredder=0.52+8.1x10 ⁻⁴ xD+0.78xT
19	CRa	% Insects	0.23	0.17	0.94	% Insects=100+4.1x10 ⁻³ xD-0.16xT
20	CRb	% Insects	0.17	0.41	0.41	% Insects= 98-6.4x10 ⁻⁴ xD-0.81xT

D= distance from cattle impact (m). T= tree presence/absence variable. The tree variable is a 0/1 variable, with 0 meaning no trees present at the site and 1 indicating trees were present. Distance p-value determines whether distance is a significant indicator variable in the model. Tree cover p-value determines whether tree cover was a significant indicator variable in the model.

* indicates significant p-value with $\alpha=0.10$. % EPT-H is the percentage of all EPT taxa minus the Hydropsychidae family out of the total number of macroinvertebrates.

EPT was also expected to increase with distance from cattle impact. Significant positive relationships between EPT scores and distance were observed for three of the four longitudinal studies (Figure 6). Distance from cattle impact was a significant predictor variable for EPT for the CRa, CRb, and SL longitudinal studies but not for MV (Table 3; lines 5-8). The lack of expected significant relationship for the MV longitudinal study could be due to the stream length (337 m) not being sufficiently long enough for improvement to occur. MV was the shortest of the four longitudinal studies. The tree variable was a significant indicator variable for EPT for

the CRa study but it did not improve the model for distance (Table 4; lines 3 & 4). As expected, EPT scores significantly increased with distance from cattle impact in most cases.

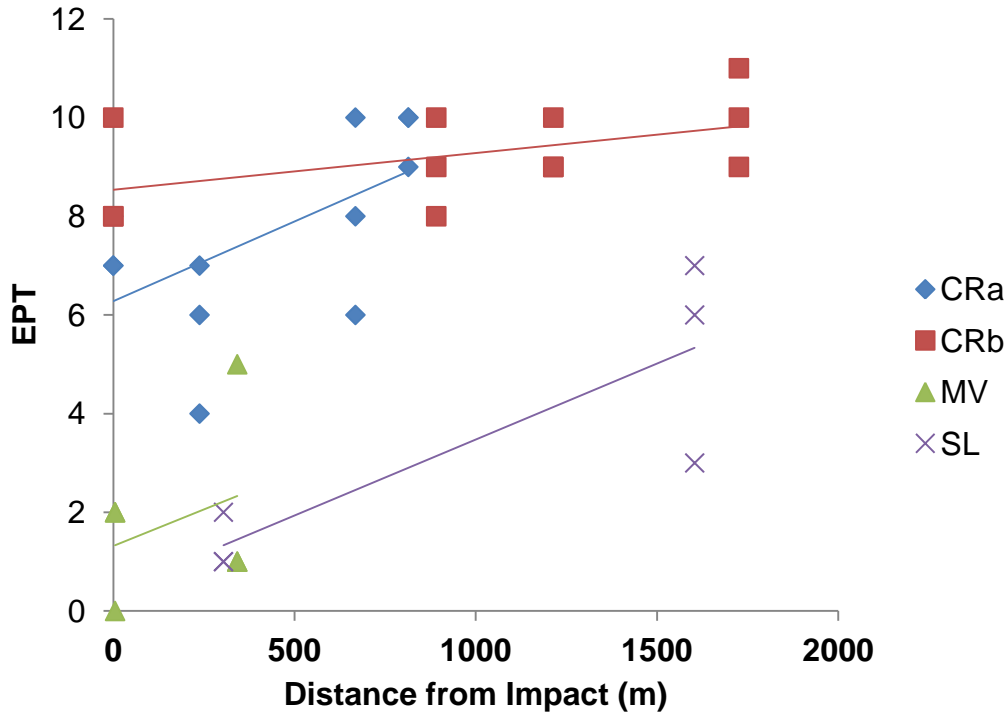


Figure 6: EPT versus downstream distance from cattle impact (m) for four stream reaches.

Richness is the total number of taxa present in each sample. This index was expected to increase with distance from cattle impact indicating improvement in biodiversity (Braccia and Voshell, 2007). Distance from impact was only a significant predictor variable for richness for one out of the four longitudinal studies, CRa (Table 3; lines 9-12; Figure 7). When the tree variable was incorporated into the model for CRa and CRb, the relationship between distance and richness was improved and became significant (Table 4; lines 5-6). Richness or biodiversity was improved by increasing distance from cattle impact and presence of trees. Also, the incorporation of the tree variable improved the model for distance vs. richness.

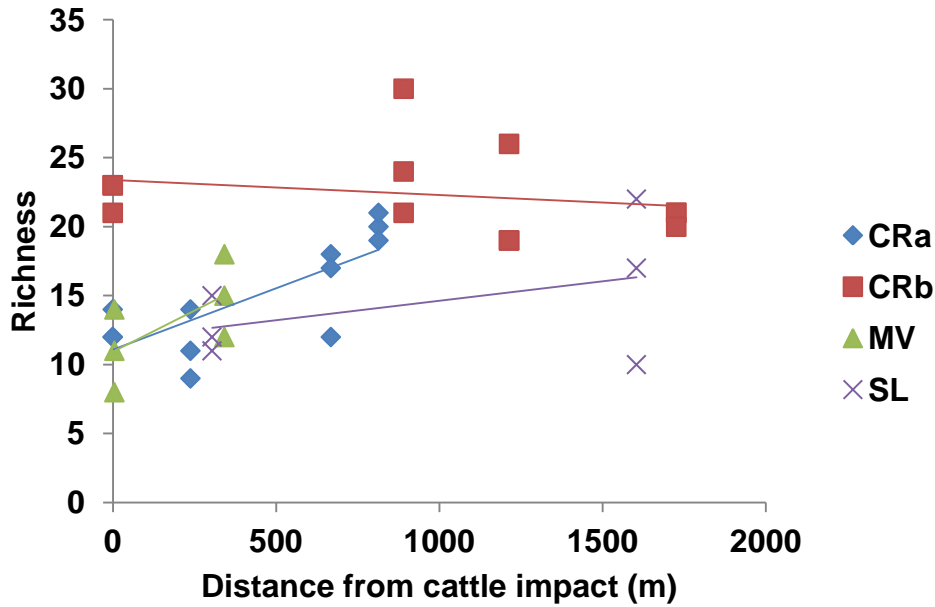


Figure 7: Taxa richness versus downstream distance from cattle impact (m) for four stream reaches.

Chironomids are a pollution tolerant family, thus a negative relationship between % chironomids and distance from cattle impact would indicate improvement (Braccia and Voshell, 2007). This negative relationship between % Chironomidae and distance was only significant for the CRa longitudinal study (Table 3; line 14). The relationship was negative but not significant for CRb (Figure 8; Table 3; line 15). The relationship between % Chironomidae and distance was *positive* for MV and SL (Table 3; line 15 & 16). This unexpected positive relationship could be due to lack of tree cover at these locations. When trees were incorporated into the model for the CRa and CRb studies the tree variable was a significant explanatory variable for % Chironomidae for both longitudinal studies, while distance was a significant explanatory variable for % Chironomidae only in the case of CRa (Table 4; lines 7 & 8). At the time of macroinvertebrate sample collection, CRb was a much more mature stream in comparison to CRa, MV, and SL. Also, cattle had been excluded longer at CRb than the other

locations. Percent Chironomidae scores for CRb are low in comparison to other sites also indicating better water quality. Due to the better stream condition at CRb, it is likely that the biological health has reached a stable condition and has thus leveled off. This would explain the lack of significant relationship between distance and % chironomidae for CRb.

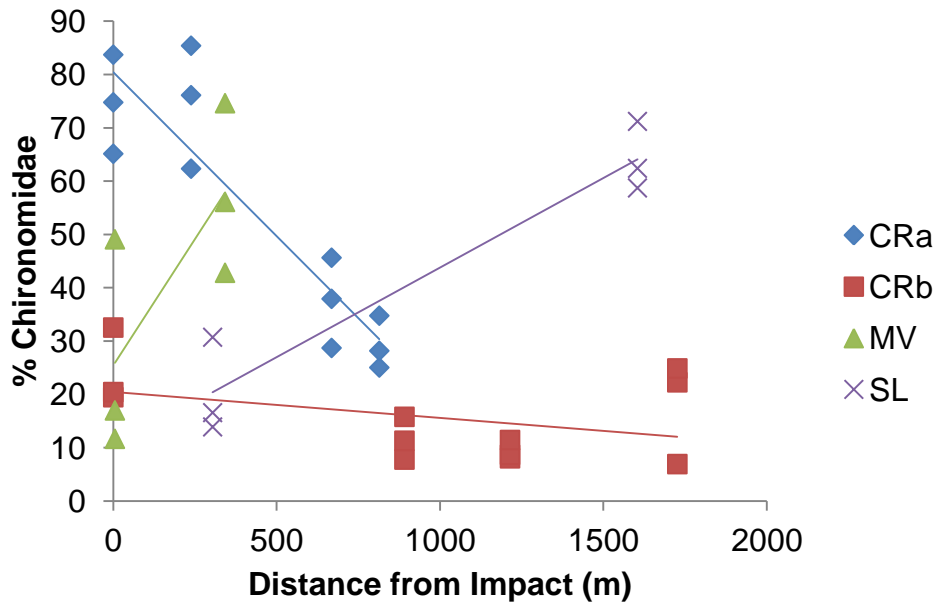


Figure 8: Percent Chironomidae vs. downstream distance from cattle impact (m) for four stream reaches.

Distance was a significant explanatory variable for % EPT for CRa and SL but not for CRb and MV (Table 3; lines 17-20). Because % EPT scores were greater for CRb than other longitudinal studies, the lack of significant improvement can again be attributed to the biological condition being at a stable ‘good’ condition due to the mature stream state. The lack of relationship between distance and % EPT for the MV longitudinal study could be due to there being insufficient downstream distance for recovery. It was the shortest of the four longitudinal studies. When trees were incorporated into the model for % EPT, again there was a significant relationship between distance and % EPT for CRa but not for CRb (Table 4; lines 9 & 10). Also,

neither longitudinal study confirmed a significant relationship between % EPT and the tree variable (Table 4; lines 9 & 10). As expected, % EPT increased with distance from impact for some of the longitudinal studies. The tree variable does not improve the model for % EPT vs. distance.

Percent EPT less Hydropsychidae (%EPT-H) was expected to be a better response variable for understanding macroinvertebrate health than % EPT because the somewhat pollution tolerant hydropsychid caddisflies are not included in the index calculation. It is expected to improve with distance from impact. A significant positive relationship between % EPT-H was present for CRa and SL (Table 3; lines 21-24; Figure 9). Incorporating the tree variable into the model slightly improved the relationship between distance and % EPT-H for CRa but not for CRb (Table 4; lines 11 & 12). Tree presence/absence however was a significant explanatory variable for % EPT-H for the CRb longitudinal study (Table 4; line 12). Again, results for CRb and MV were not as expected, possibly due to the mature biological condition and insufficient distance necessary for recovery. Based on this macroinvertebrate index, it does not seem as if the tree variable improves the model for % EPT-H vs. distance from cattle impacts. Just as with % EPT, %EPT-H scores increased with distance from impact for some of the longitudinal studies. However, % EPT-H did not appear to be a better index for assessing macroinvertebrate health than % EPT.

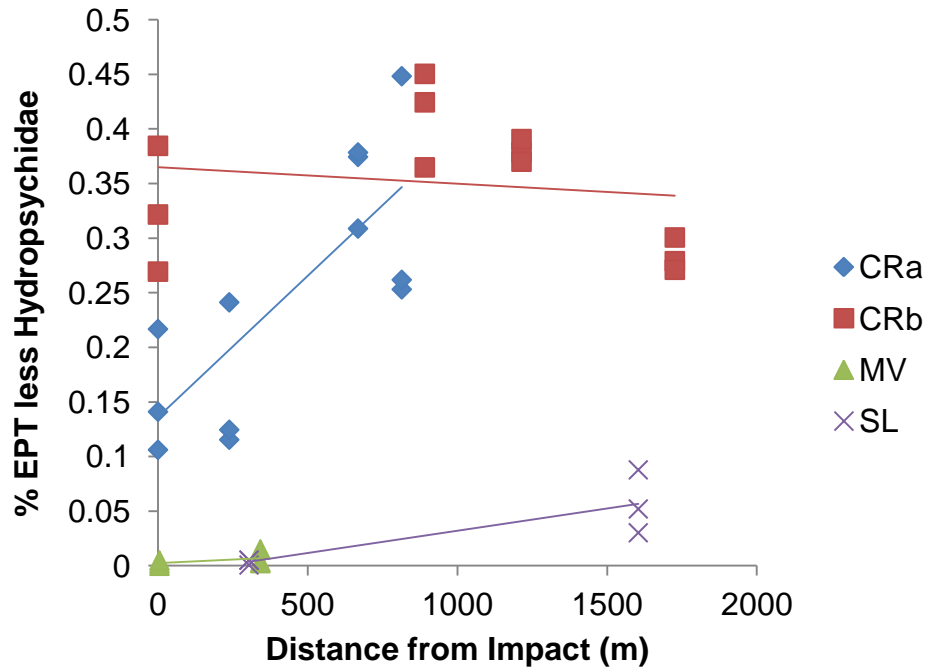


Figure 9: Percent EPT less Hydropsychidae versus downstream distance from cattle impact (m) for four stream reaches.

Based on the regression model, % scraper was not consistently related to increasing distance from cattle impacts. However, % filterer was positively related to distance from cattle impacts for CRa ($r^2=0.328$), MV ($r^2=0.709$), and SL ($r^2=0.882$) (Table 3; lines 29, 31, & 32). It was expected that filterer taxa would be more dominant in locations closer to cattle impacts (Braccia and Voshell, 2007); thus a negative relationship was expected. The observed positive relationship could indicate that the stream just has greater biodiversity with increasing distance from the impact.

Percent shredder was expected to increase with increasing distance from cattle impacts due to the theoretical increase in organic matter inputs to the stream (Braccia and Voshell, 2007). A positive relationship between % shredder and distance from cattle impact was significant for the CRa ($r^2=0.301$), CRb ($r^2=0.283$), and MV ($r^2=0.555$) study sites (Table 3; lines 33, 34, & 35).

The lack of significant positive relationship for the SL study could be due to the lack of tree cover along that reach (Table 3; line 36).

Percent insect density was expected to increase with improving stream condition (Stone *et. al* 2005). Therefore, it was expected to increase with distance from impact. This positive relationship between distance and % insects was significant for the MV and SL longitudinal studies but not for CRa and CRb (Table 3; lines 37-40). The lack of significant relationship between distance and % insects for CRa and CRb could be due to these stream segments reaching a stable condition. This conclusion is supported by observed intercept values of around 100% for these two locations (Table 3; lines 39 & 40).

The objective of the longitudinal macroinvertebrate studies was to determine whether improvement in benthic macroinvertebrate populations occurred with increasing downstream distance from cattle-impacted stream segments. We predicted that downstream improvements would occur in benthic macroinvertebrate assemblage in reaches where cattle were excluded. The results based on the CRa and CRb studies clearly indicated that improvement occurred as hypothesized, based on VASCI, EPT, and Richness indices, which are the most commonly used indices. It was also apparent that the presence of trees helped to improve benthic macroinvertebrate index scores. Therefore, to see the expected benefits of cattle exclusion on the biological community of streams, it is recommended that trees be planted.

Multilevel modeling was used to incorporate random effects and make inferences about the population of streams rather than just the individual streams that were studied. A multilevel model was fit to explain the Virginia Stream Condition Index (VASCI) data, which included distance from cattle impacts (m), tree cover (presence/absence), and discharge (m^3/s) as predictor

variables (Equation 1; T[0/1]=tree absence/presence; D=distance from impact in meters; Q=discharge (m³/s)).

$$\text{VASCI} = 29.69 + 8.53 \times T [0/1] + 0.025 \times D + 162.20 \times Q \quad (1)$$

The threshold of t-value > 1.5 indicated that a predictor variable within the model was significant and useful in the model. Both distance from impact and tree cover were found to be significant (t-values = 2.396 and 2.710 respectively), while discharge was not a significant indicator variable (t-value = 0.899). Therefore, another model for VASCI that only included distance from cattle impact and tree cover as predictor variables was created as follows:

$$\text{VASCI} = 32.95 + 10.87 \times T [0/1] + 0.023 \times D \quad (2)$$

Both distance from impact and tree cover were significant predictor values for VASCI [t-value (distance) = 2.454; t-value (tree) = 3.735]. Equation 2 can theoretically be used to determine the distance of cattle exclusion necessary to achieve a certain VASCI score for other streams.

Longitudinal RHA Studies

Physical habitat conditions were also examined with increasing downstream distance from cattle-impacted stream segments. This was only done for the CRa and CRb longitudinal sites because the MV and SL sites consisted of only 2 points with 1 replicate. Total RHA, embeddedness, bank stability, bank vegetative protection, and riparian vegetative zone width were used to represent physical habitat conditions because these parameters were expected to be most influenced by cattle impacts.

Individual simple linear regression models for distance from cattle impact vs. total RHA and RHA parameters (that are relevant for examining cattle impacts) were created to examine the relationship between physical conditions and distance from cattle impact (Table 5). Based on the individual simple linear regression results, distance from cattle impact is not a significant

predictor variable for any of the RHA parameters examined or the total RHA (Table 5; p-value column). An explanation for this lack of correlation with RHA and distance could be that cattle must be present in the stream channel to do much physical damage. Embeddedness is the only factor RHA examines that can possibly be attributed to upstream influences. However, embeddedness did not significantly improve with distance from impact (Table 5; lines 1 & 2). The bank stability, bank vegetative cover, and riparian vegetative zone parameters only examine local effects and therefore should not be expected to vary longitudinally.

Table 5: Linear regression results for downstream distance from cattle impact versus RHA parameters.

	Site Name	RHA Parameter	r²	p-value: distance	Equation
1	CRa	Embeddedness	0.061	0.7354	$E=13.3+1.12 \times 10^{-3} \times d$
2	CRb	Embeddedness	0.413	0.3573	$E=10.2+6.35 \times 10^{-3} \times d$
3	CRa	Bank Stability	0.566	0.2478	$BS=19.6-1.91 \times 10^{-3} \times d$
4	CRb	Bank Stability	0.026	0.8390	$BS=19.8-1.59 \times 10^{-4} \times d$
5	CRa	Bank Veg. Protection	0.280	0.4705	$VP=16.2+3.70 \times 10^{-3} \times d$
6	CRb	Bank Veg. Protection	1	***	$VP=20+0 \times d$
7	CRa	Rip. Veg. Zone	0.031	0.8223	$RZ=5.43+1.33 \times 10^{-3} \times d$
8	CRb	Rip. Veg. Zone	0.617	0.2146	$RZ=7.45+8.65 \times 10^{-3} \times d$
9	CRa	Total RHA	0.377	0.3862	$RHA=155+0.0104 \times d$
10	CRb	Total RHA	0.689	0.1702	$RHA=160.+0.0157 \times d$

d=distance from cattle impact (m). Distance p-value indicates whether distance is a significant indicator variable in the model. * indicates significant p-value with $\alpha=0.10$. ***All data for this point was the same value (20: maximum possible vegetation protection score).

The objective of the longitudinal RHA studies was to determine whether improvement of physical habitat conditions occurred with increasing downstream distance from cattle-impacted stream segments. It was predicted that there would not be improvements in physical habitat with increasing distance from impact where cattle were excluded. The results of the longitudinal RHA studies confirm this prediction. None of the physical habitat parameters evaluated varied with distance. This is because physical degradations are the result of local impacts rather than

upstream impacts, and cattle exclusion prevented local degradation along the longitudinal study reaches.

Rapid Habitat Assessment

RHA scores were grouped based on the presence, absence, or intermittent presence of cattle at the site to better understand how the scores differed as a result of cattle impacts (Figure 10). No significant differences were present between cattle classification groups based on the channel alteration, channel flow status, epifaunal substrate/available cover, frequency of riffles, sediment deposition, or velocity/depth regime parameters. However, for the bank stability RHA parameter, the no-cattle sites were significantly different from the cattle sites (p-value=0.0005), and the intermittent sites were significantly different from the cattle sites (p-value=0.0298). For embeddedness, the no-cattle and cattle sites were significantly different (p-value=0.0820). No-cattle and cattle sites were significantly different based on the riparian vegetative zone width parameter (p-value=0.0007). Based on the bank vegetative protection parameter, cattle sites were significantly different from intermittent access sites (p-value=0.0046), and cattle sites were also significantly different from no-cattle sites (p-value=0.0009). The results indicated that bank stability, embeddedness, riparian vegetative zone width, and bank vegetative protection were the most useful parameters within RHA for characterizing impacts of cattle upon streams.

It should be noted that the riparian vegetative zone width parameter is not likely to be *directly* impacted by cattle. This RHA parameter assesses tree cover, and in most cases larger trees are not killed by cattle presence. Usually, if there are no trees in a pasture, it's because the pasture was previously cleared by humans. Therefore, even though cattle were associated with decreases in riparian vegetative zone width they are not the cause of the decrease.

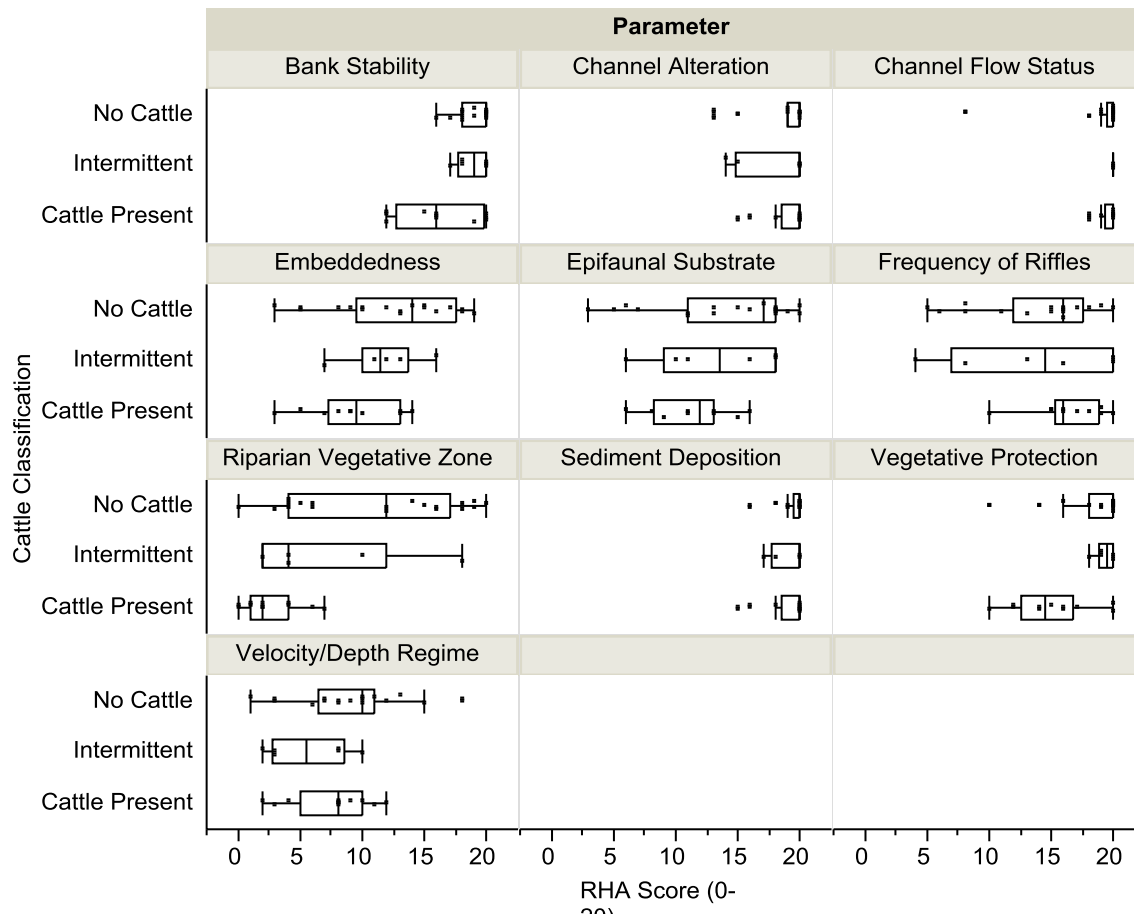


Figure 10: Distributions of RHA parameters based on cattle classification separated by RHA sub-parameter. Significant differences were found between the no-cattle and cattle groups for bank stability, embeddedness, riparian vegetative zone width, and vegetative protection parameters.

Total RHA scores were also grouped based on the presence, absence, or intermittent presence of cattle at the site to better understand how the total scores differed as a result of cattle impacts (Figure 11). Based on the total RHA score, which incorporates all ten parameters, the cattle and no-cattle sites were significantly different ($p\text{-value}=0.0166$). Therefore, despite the fact that not all of the parameters within RHA are useful in characterizing cattle impacts, this method as a whole was still useful in measuring the impacts of cattle upon streams. The presence or absence of cattle differentiated between the total RHA scores as well as the scores for the four

previously mentioned parameters. Therefore, in cattle-impacted streams, the bank stability, embeddedness, riparian vegetative zone width, and bank vegetative protection parameters had more weight towards the total RHA score.

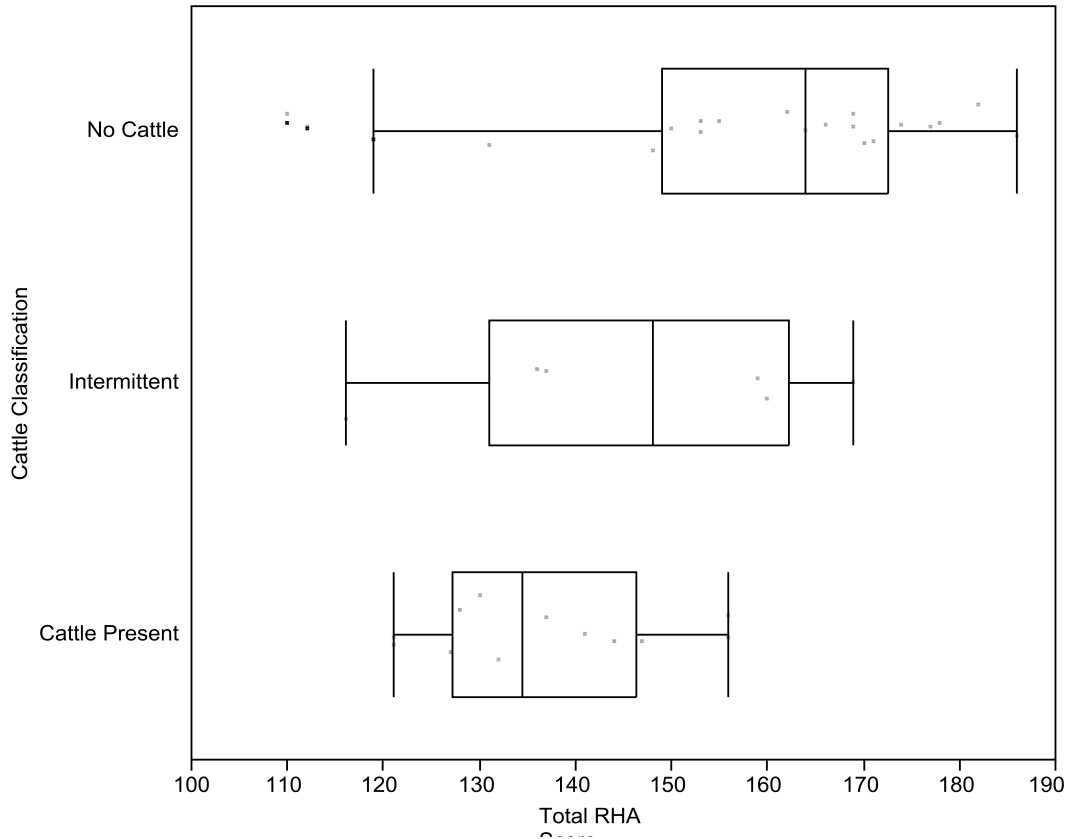


Figure 11: Distributions of total RHA scores based on cattle classification. The total score incorporates all 10 sub-parameters.

The objective of the Rapid Habitat Assessment evaluation was to determine which physical habitat parameters were most affected by cattle impacts. It was expected that certain parameters within the total RHA evaluation would be more pertinent for the examination of cattle-impacted streams than others. The results validated this hypothesis and indicated that embeddedness, bank stability, bank vegetative protection, and riparian vegetative zone width

were the best parameters for examining cattle impacts. The results also indicated that the total RHA score was valuable for characterizing cattle impacts.

Water Quality Metric Evaluation

Multivariate comparisons were made among the following water quality measures for all locations where macroinvertebrates were collected in Rockingham County: TSS (mg/L), turbidity (NTU), conductivity (mg/L), RHA, VASCI, EPT, total N (mg/L), total P (mg/L), and *E. coli* (average MPN) (Table 6). To determine which water quality metrics could be used to understand macroinvertebrate health, correlations between water quality metrics and macroinvertebrate metrics (VASCI and EPT) were examined. Based on the data from macroinvertebrate sites, the strongest correlations (using $\alpha=0.10$ to indicate significance) were between: VASCI and RHA ($r=0.4559$), EPT and TSS ($r=-0.5746$), EPT and turbidity ($r=-0.5729$), EPT and conductivity ($r=-0.4950$), EPT and RHA ($r=0.7033$), EPT and VASCI ($r=0.7245$), EPT and total P ($r=-0.6571$), and EPT and *E. coli* ($r=-0.4023$) (Table 6). RHA was positively correlated with both bioassessment indices, EPT and VASCI. Therefore, based on this dataset, higher physical habitat quality was related to better biological condition of streams. Since RHA was the only water quality measure correlated with both VASCI and EPT, it suggests that RHA is the most useful water quality parameter to measure if trying to assess stream biological condition without actual biomonitoring. However, since RHA is a subjective method that takes skill and practice to perform accurately, it would be better to use a non-subjective measure that is also correlated with macroinvertebrate results such as turbidity, TSS, conductivity, or total P.

Table 6: Pair-wise correlation of water quality metrics collected from sample locations in Rockingham County, VA.

Variable	By Variable	R	Count	Signif. Prob.
Turbidity (NTU)	TSS (mg/L)	0.97	20	<0.01*
Econductivity (mg/L)	TSS (mg/L)	0.51	20	0.02*
Econductivity (mg/L)	Turbidity (NTU)	0.54	20	0.01*
RHA	TSS (mg/L)	-0.57	19	0.01*
RHA	Turbidity (NTU)	-0.58	19	<0.01*
RHA	Econductivity (mg/L)	-0.30	19	0.22
VASCI	TSS (mg/L)	0.20	20	0.40
VASCI	Turbidity (NTU)	0.15	20	0.54
VASCI	Econductivity (mg/L)	0.01	20	0.98
VASCI	RHA	0.46	23	0.03*
EPT	TSS (mg/L)	-0.58	20	<0.01*
EPT	Turbidity (NTU)	-0.57	20	<0.01*
EPT	Econductivity (mg/L)	-0.50	20	0.03*
EPT	RHA	0.70	23	<0.01*
EPT	VASCI	0.72	24	<0.01*
Total N (mg/L)	TSS (mg/L)	0.35	15	0.21
Total N (mg/L)	Turbidity (NTU)	0.47	15	0.07*
Total N (mg/L)	Econductivity (mg/L)	0.32	15	0.24
Total N (mg/L)	RHA	-0.52	14	0.05*
Total N (mg/L)	VASCI	-0.06	15	0.83
Total N (mg/L)	EPT	-0.33	15	0.23
Total P (mg/L)	TSS (mg/L)	0.89	15	<0.01*
Total P (mg/L)	Turbidity (NTU)	0.83	15	<0.01*
Total P (mg/L)	Econductivity (mg/L)	0.54	15	0.04*
Total P (mg/L)	RHA	-0.60	14	0.02*
Total P (mg/L)	VASCI	0.38	15	0.16
Total P (mg/L)	EPT	-0.66	15	<0.01*
Total P (mg/L)	Total N (mg/L)	0.34	15	0.22
E. Coli Avg. MPN	TSS (mg/L)	0.41	20	0.08*
E. Coli Avg. MPN	Turbidity (NTU)	0.45	20	0.05*
E. Coli Avg. MPN	Econductivity (mg/L)	0.17	20	0.48
E. Coli Avg. MPN	RHA	-0.30	23	0.17
E. Coli Avg. MPN	VASCI	-0.05	24	0.81
E. Coli Avg. MPN	EPT	-0.40	24	0.05*
E. Coli Avg. MPN	Total N (mg/L)	-0.07	15	0.80
E. Coli Avg. MPN	Total P (mg/L)	0.58	15	0.02*

r= correlation coefficient. *correlation significant at $\alpha=0.10$.

For the selected ProbMon data from the Shenandoah Valley, the strongest correlations were between: VASCI and conductivity ($r=0.4330$), EPT and conductivity ($r=-0.6043$), EPT and VASCI ($r=0.7601$), EPT and total N ($r=-0.6217$), and EPT and total P ($r=-0.5814$) (Table 7).

The correlation results based on ProbMon data differed from the results from data collected at

our sample sites in Rockingham County. The differences in correlations for the two datasets could be due to most of our sites having cattle impacts while the ProbMon sites were randomly chosen. ProbMon results indicated that conductivity, total N, and total P were most highly correlated with macroinvertebrate metrics.

Table 7: Pair-wise correlation of water quality metrics from ProbMon sample locations in the Shenandoah Valley, VA.

Variable	By Variable	R	Count	Signif. Prob.
Turbidity (NTU)	TSS (mg/L)	0.05	20	0.83
E conductivity (mg/L)	TSS (mg/L)	0.38	20	<0.01*
E conductivity (mg/L)	Turbidity (NTU)	0.36	20	0.12
RHA	TSS (mg/L)	0.25	16	0.35
RHA	Turbidity (NTU)	-0.01	16	0.97
RHA	E conductivity (mg/L)	0.21	16	0.44
VASCI	TSS (mg/L)	-0.19	19	0.44
VASCI	Turbidity (NTU)	0.06	19	0.82
VASCI	E conductivity (mg/L)	-0.43	19	0.06*
VASCI	RHA	-0.39	15	0.16
EPT	TSS (mg/L)	-0.01	19	0.97
EPT	Turbidity (NTU)	-0.22	19	0.36
EPT	E conductivity (mg/L)	-0.60	19	<0.01*
EPT	RHA	-0.33	15	0.23
EPT	VASCI	0.76	19	<0.01*
Total N (mg/L)	TSS (mg/L)	0.10	20	0.68
Total N (mg/L)	Turbidity (NTU)	0.57	20	<0.01*
Total N (mg/L)	E conductivity (mg/L)	0.70	20	<0.01*
Total N (mg/L)	RHA	0.15	16	0.59
Total N (mg/L)	VASCI	-0.38	19	0.10
Total N (mg/L)	EPT	-0.62	19	<0.01*
Total P (mg/L)	TSS (mg/L)	0.03	20	0.89
Total P (mg/L)	Turbidity (NTU)	0.58	20	<0.01*
Total P (mg/L)	E conductivity (mg/L)	0.65	20	<0.01*
Total P (mg/L)	RHA	-0.13	16	0.64
Total P (mg/L)	VASCI	-0.22	19	0.38
Total P (mg/L)	EPT	-0.58	19	<0.01*
Total P (mg/L)	Total N (mg/L)	0.78	20	<0.01*

r= correlation coefficient. * correlation significant at $\alpha=0.10$.

Additionally, all data from ProbMon and our sample sites in Rockingham County was combined to examine pair wise correlations between water quality metrics and biological metrics

(Table 8). The strongest correlations were between: VASCI and conductivity ($r=-0.7007$), VASCI and RHA ($r=0.3017$), EPT and turbidity ($r=-0.5478$), EPT and conductivity ($r=-0.7252$), EPT and RHA ($r=0.4487$), EPT and VASCI ($r=0.7900$), VASCI and total N ($r=-0.6377$), and EPT and total N ($r=-0.6796$) (Table 8).

Table 8: Pair-wise correlation of water quality metrics for combined sample data and ProbMon data.

Variable	By Variable	R	Count	Signif. Prob.
Turbidity (NTU)	TSS (mg/L)	0.14	40	0.39
E conductivity (mg/L)	TSS (mg/L)	0.13	40	0.41
E conductivity (mg/L)	Turbidity (NTU)	0.48	40	<0.01*
RHA	TSS (mg/L)	0.11	35	0.54
RHA	Turbidity (NTU)	-0.52	35	<0.01*
RHA	E conductivity (mg/L)	-0.25	35	0.14
VASCI	TSS (mg/L)	-0.01	39	0.93
VASCI	Turbidity (NTU)	-0.24	39	0.15
VASCI	E conductivity (mg/L)	-0.70	39	<0.01*
VASCI	RHA	0.30	38	0.07*
EPT	TSS (mg/L)	-0.04	39	0.83
EPT	Turbidity (NTU)	-0.55	39	<0.01*
EPT	E conductivity (mg/L)	-0.73	39	<0.01*
EPT	RHA	0.45	38	<0.01*
EPT	VASCI	0.79	43	<0.01*
Total N (mg/L)	TSS (mg/L)	-0.04	35	0.84
Total N (mg/L)	Turbidity (NTU)	0.60	35	<0.01*
Total N (mg/L)	E conductivity (mg/L)	0.73	35	<0.01*
Total N (mg/L)	RHA	-0.52	30	<0.01*
Total N (mg/L)	VASCI	-0.64	34	<0.01*
Total N (mg/L)	EPT	-0.68	34	<0.01*
Total P (mg/L)	TSS (mg/L)	0.11	35	0.52
Total P (mg/L)	Turbidity (NTU)	0.78	35	<0.01*
Total P (mg/L)	E conductivity (mg/L)	0.53	35	<0.01*
Total P (mg/L)	RHA	-0.48	30	<0.01*
Total P (mg/L)	VASCI	-0.19	34	0.30
Total P (mg/L)	EPT	-0.62	34	<0.01*
Total P (mg/L)	Total N (mg/L)	0.51	35	<0.01*
E. coli (Avg MPN)	TSS (mg/L)	0.41	20	0.08*
E. coli (Avg MPN)	Turbidity (NTU)	0.45	20	0.05*
E. coli (Avg MPN)	E conductivity (mg/L)	0.17	20	0.48
E. coli (Avg MPN)	RHA	-0.30	23	0.17
E. coli (Avg MPN)	VASCI	-0.05	24	0.81
E. coli (Avg MPN)	EPT	-0.40	24	0.05
E. coli (Avg MPN)	Total N (mg/L)	-0.07	15	0.80
E. coli (Avg MPN)	Total P (mg/L)	0.58	15	0.02*

r= correlation coefficient. * correlation significant at $\alpha=0.10$.

The objective of the water quality correlation study was to evaluate metrics for characterizing cattle impacts on stream quality. It was hypothesized that a correlation would exist between biomonitoring results and other water quality parameters, which could be used to more easily assess the impact of cattle on streams. As expected, macroinvertebrate metrics were

correlated with many other water quality metrics. This was expected because macroinvertebrates are indicators of the physical, chemical, and biological quality of streams (Stone et al., 2005). The correlation results from the 24 macroinvertebrate locations were slightly different from the results from the ProbMon locations. Based on the combined water quality data it appears that conductivity, turbidity, RHA, total N, and total P are correlated with macroinvertebrate data. Therefore, such physical and chemical water quality measures can be used to understand the biological health of a stream without doing a highly time-consuming biological assessment.

Summary and Conclusions

In this study, the effects of cattle exclusion on stream habitat were examined in the Shenandoah Valley, Virginia. Four longitudinal studies were used to determine the improvement of physical habitat conditions and benthic macroinvertebrate populations with increasing downstream distance from cattle-impacted stream segments. The conclusions are:

- Improvement in macroinvertebrate assemblage occurred with increasing distance downstream of cattle-impacted reaches.
- Presence of trees and distance from impact had a positive influence on bioassessment scores.
- Specific improvements in VASCI as a function of distance from cattle exclusion can be predicted based on the developed model.
- Physical habitat conditions were not related to distance from cattle impacts because cattle mostly cause local physical habitat damage and minimal downstream physical habitat damage.

In order to determine which physical habitat parameters were most affected by cattle impacts, habitat quality was examined by applying Rapid Habitat Assessment to a range of streams with either cattle presence, absence, or intermittent cattle presence. We concluded that:

- Embeddedness, bank stability, bank vegetative protection, and riparian vegetative zone width are the most responsive parameters to cattle impacts out of all ten RHA parameters. Therefore land managers can focus on these variables to determine where cattle exclusion fencing will potentially improve stream condition.
- The total RHA score is also correlated to cattle presence.

In order to examine which water quality measures were most highly related to the biological condition of streams, correlations between multiple parameters were analyzed. We concluded that:

- Information about the biological condition can be inferred based on conductivity, turbidity, RHA, total N, and total P which had the strongest correlations with macroinvertebrate scores.
- As expected, significant correlations existed between macroinvertebrate results and other chemical and physical stream quality metrics. These metrics can thus be used to make inferences about the biological condition of streams.
- However, it is important that biomonitoring is not replaced by physical and chemical monitoring because bioassessment studies give information about the physical, chemical, and biological health of streams throughout the watershed over time.

The results of this study have demonstrated the effects of cattle exclusion on stream habitat in the Shenandoah Valley, Virginia. It will hopefully improve water quality in the Chesapeake Bay watershed by assisting future cattle exclusion management practices in determining which streams are most degraded and in need of cattle exclusion, and also give an indication about the distance of exclusion necessary to improve stream habitat to a specified level.

Future studies are needed to validate the model developed to predict VASCI with downstream distance from cattle impacts. The model's effectiveness at predicting VASCI scores based on distance from cattle impact would need to be tested at other streams. Another recommendation is to conduct longitudinal studies with longer distances to better understand the relationship between habitat quality and distance from cattle impact. In addition, the influence of

years since cattle exclusion on improvement in stream condition should be assessed, with the goal of determining whether the improvement becomes more distinct (and the slope increases) or levels off and comes to a steady state equilibrium condition with greater time. Lastly, the relationships between macroinvertebrate scores and other water quality parameters could be explored using linear regression as a model to define relationships.

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Appendix A. Macroinvertebrate data for each sample

At each of the stream sampling sites, three replicate samples were collected, and each of these samples was analyzed individually. In the tables below, the replicate number is added to the site ID following the colon to give a unique sample ID. Thus, SL1:1 and SL1:2 represent two of the replicate samples at site SL1. Feeding groups, EPT taxa, and tolerance values were assigned based on Burton and Gerritsen (2003) and Voshell (2002). Identification of macroinvertebrates was done with *A Guide to Common Freshwater Invertebrates of North America*, by J. Reese Voshell (2002).

Table A-1: Macroinvertebrate counts for each sample.

Macroinvertebrate Name	Feeding Group	Insect (y/n)	Tolerance Value	EPT Taxa	CR1a:1	CR1a:2	CR1a:3	CR2:1	CR2:2
Amphipoda	Shredder	N	6						
Asellidae	Collector	N	8						
Baetidae	Collector	y	4	E	11		43		10
Bithyniidae	Scraper	N	6						
Blephariceridae	Scraper	Y	0						
Brachycentridae	Filterer	Y	1	T					
Caenidae	Collector	Y	4	E					
Cambaridae	Shredder	N	5		0	1		0	0
Ceratopogonidae	Predator	Y	6						1
Chironomidae	Collector	Y	7.5		634	647	592	444	379
Chloroperlidae	Predator	Y	1	P		5	14	4	
Coenagrionidae	Predator	Y	9						
Corbiculidae	Filterer	N	8						
Corydalidae	Predator	Y	5						
Culicidae	Filterer	Y	8		103		58		32
Dixidae	Collector	Y	2						
Dytiscidae	Predator	Y	6					1	
Elmidae	Scraper	Y	4		4	12	18	1	
Empididae	Predator	Y	6						
Ephemerellidae	Collector	Y	4	E	21	42	65	39	27
Ephemeridae	Collector	Y	4	E					
Ephyridae	Collector	Y	7						
Glossomatidae	Scraper	Y	0	T					
Halipilidae	Shredder	Y	7			1	1		
Helicopsychidae	Shredder	Y	3	T					
Heptageniidae	Scraper	Y	4	E	5		5		6
Hirudinea	Predator	N	7						
Hydrachnida	Predator	N	5						
Hydrobiidae	Scraper	N	3						
Hydrophilidae	Predator	Y	5						
Hydropsychidae	Filterer	Y	6	T	1	2	24	11	22
Hydroptilidae	Scraper	Y	6	T	1				
Isonychiidae	Filterer	Y	3	E					
Lepidostomatidae	Shredder	Y	1	T					
Leptoceridae	Collector	Y	4	T					
Leptohiphidae	Collector	Y	3	E					
Leptophlebiidae	Collector	Y	2	E	44	47	58	17	14
Leuctridae	Shredder	Y	0	P		10			
Linnephilidae	Shredder	Y	4	T					
Lymnaeidae	Scraper	N	7						
Nemouridae	Shredder	Y	2				1		
Notonectidae	predator	Y	10						
Odontoceridae	Scraper	Y	0	T		3	11		
Oligochaeta	Collector	N	10					1	
Palaemonidae		N	5					2	
Peltoperlidae	Shredder	Y	2	P					
Perlidae	Predator	Y	1	P	8				5
Philopotamidae	collector	Y	3	T					
Physidae	Scraper	N	8						
Planorbidae	Scraper	N	7						
Pleuroceridae	Scraper	N	4						
Psephenidae	Scraper	Y	4						
Rhyacophilidae	Predator	Y	0	T		2			
Sialidae	Predator	Y	4						
Simuliidae	Filterer	Y	6		2		7		
Sphaeriidae	Filterer	N	8						
Stratiomyidae	collector	Y	10						
Tipulidae	Shredder	Y	3		14	1	12		1
Turbellaria	Predator	N	6						
Unionidae	Filterer	N	4						
Viviparidae	Scraper	N	3						

Table A-1: Macroinvertebrate counts - cont.

Macroinvertebrate Name	CR2: 3	CR3: 1	CR3: 2	CR3: 3	CR4: 1	CR4: 2	CR4: 3	CR6: 1	CR6: 2	CR6: 3	CR7: 1	CR7: 2	CR7: 3
Amphipoda													
Asellidae						7		1		1	2		
Baetidae	15	18	68	69	64	35	45	304	281	271	101	401	462
Bithyniidae								8					
Blephariceridae													
Brachycentridae												1	
Caenidae								1					
Cambaridae	1	1			1		1	0	1	1	1		
Ceratopogonidae					1				1			1	1
Chironomidae	230	234	261	507	138	206	243	233	383	177	36	188	106
Chloroperlidae	9	14	6	11	18	13	2						
Coenagrionidae								1	2		1	1	7
Corbiculidae								1		5		3	2
Corydalidae			3	5	1		1					1	
Culicidae	24		13	40	3	20	14		31	7	3	4	
Dixidae													
Dytiscidae													
Elmidae	9	56	102	73	68	88	40	247	204	31	68	129	337
Empididae								1	8	1			
Ephemerellidae	16	92	131	99	38	59	23	4		6	1	3	9
Ephemeridae													
Ephyridae													
Glossomatidae											1		
Halipilidae													1
Helicopsychidae												2	
Heptageniidae	16		9	5	39	15	30	20	10	11	5	9	9
Hirudinea								2				3	3
Hydrachnida				2	1	1	2					3	5
Hydrobiidae													
Hydrophilidae									1			5	
Hydropsychidae	10	62	83	95	36	97	111	217	199	281	36	228	231
Hydroptilidae						2			1				
Isonychiidae					1				6	8		4	5
Lepidostomatidae													
Leptoceridae													
Leptoxyphidae								3	10	4	1	54	30
Leptophlebiidae	31	101	109	150	55	40	75	24					
Leuctridae		6						1		5			
Linnephilidae			5		6	4	3					2	4
Lymnaeidae								1				3	
Nemouridae													
Notonectidae												1	
Odontoceridae	2		2					3					
Oligochaeta	2										1	7	
Palaemonidae									1				
Peltoperlidae													
Perlidae			9	3	6	3	2	8	4		4		1
Philopotamidae			5	6	20	14		20	5	28	3	60	58
Physidae													1
Planorbidae					3	1		2			1	1	
Pleuroceridae													
Psephenidae		14	24	8	25	6	23	25	12	9	31	18	40
Rhyacophilidae													
Sialidae					1	3			1				
Simuliidae	2	17	62	8	5	49		59	8	4	1	8	6
Sphaeriidae					4	64		6		1			2
Stratiomyidae													
Tipulidae	2	2	15	29	13		75		3	2	11	13	22
Turbellaria								10	2	1	6	23	7
Unionidae												1	
Viviparidae			2	1	4	4	4		3	12	4	13	13

Table A-1. Macroinvertebrate counts – contd.

Macroinvertebrate Name	CR8: 1	CR8: 2	CR8: 3	CR9: 1	CR9: 2	CR9: 3	LN3: 1	LN3: 2	LN3: 3	LN4: 1	LN4: 2	LW5: 1	LW5: 2
Amphipoda		2											
Asellidae		3	4	1		10		2	3	407	2354	75	72
Baetidae	120	172	85	68	208	80	1		5	2	7	2	1
Bithyniidae													
Blephariceridae							2						
Brachycentridae													
Caenidae		1											
Cambaridae	0		1	0	1		0	0	1	0			2
Ceratopogonidae					1					2			
Chironomidae	39	54	52	72	278	390	95	28	73	11	239	273	203
Chloroperlidae													
Coenagrionidae	3	1	4										
Corbiculidae				14									
Corydalidae	1	3	2										
Culicidae		2		3	16	17	15	5	13	2	15	30	
Dixidae													
Dytiscidae										1			
Elmidae	97	140	57	251	234	261	1	3	2	36	66	148	92
Emphididae		1										1	
Ephemerellidae	5	23	19	19	45	22							
Ephemeridae			1	1									
Ephydriidae													
Glossomatidae											1		
Halipilidae		1											
Helicopsychidae				1									
Heptageniidae	13	25	13	4	6	19				5	35	1	
Hirudinea		1			1								
Hydrachnida		1			2	2					5		
Hydrobiidae													
Hydrophilidae													
Hydropsychidae	126	140	156	313	329	374	4	11	2		73	5	8
Hydroptilidae					4		4				1	2	
Isonychiidae		1	13	1	2	6							
Lepidostomatidae													
Leptoceridae													
Leptohyphidae	6	7	21	4	21	3							
Leptophlebiidae	17									5	4		
Leuctridae													
Linnephilidae		5	6		6	35							
Lymnaeidae													
Nemouridae													
Notonectidae													
Odontoceridae				14									
Oligochaeta						4		42	77	3	4	2	
Palaemonidae							1			2			
Peltoperlidae	1												
Perlidae	1	3		4	2	2					3		
Philopotamidae	21	6	10	196	54	258		1		1	3		
Physidae									3				
Planorbidae	1						2	1	6				
Pleuroceridae													
Psephenidae	6	3	2	27	6	11							
Rhyacophilidae													
Sialidae	4				8								
Simuliidae		11	3	6		10	1215	255	79	3	803	16	1
Sphaeriidae	2	1		2		1	1				2		
Stratiomyidae													
Tipulidae	7	5	2	4	23	13			1		1	10	
Turbellaria				33		50						15	16
Unionidae													
Viviparidae	16	10	3		1								

Table A-1. Macroinvertebrate counts – contd.

Macroinvertebrate Name	LW5: 3	LW6: 1	LW6: 2	LW6: 3	MC1: 1	MC1: 2	MC1: 3	MC2: 1	MC2: 2	MC2: 3	MCG: 1	MCG: 2
Amphipoda												
Asellidae	71	276	338	67	136	137	211		5	7	7	15
Baetidae	10	10	7	2		6	5		24	12	63	76
Bithyniidae												
Blephariceridae												
Brachycentridae												
Caenidae												
Cambaridae	0	0	0			0		0		0	0	
Ceratopogonidae			1									
Chironomidae	253	558	605	242	21	228	12	47	128	58	130	83
Chloroperlidae												
Coenagrionidae												
Corbiculidae												
Corydalidae												
Culicidae		75	66	48	2	15	19	8	27	9		15
Dixidae												
Dytiscidae												
Elmidae	130	77	55	75	4	3	9	24	109	79	33	27
Emphididae						1						
Ephemerellidae		1								1		
Ephemeridae												
Ephyridae												
Glossomatidae												
Halipilidae												
Helicopsychidae												
Heptageniidae		1	4	2				3	12	5		
Hirudinea												
Hydrachnida		11	8	1							1	
Hydrobiidae		1				6						
Hydrophilidae												
Hydropsychidae	3	23	12	3	6	36	59	29		58	50	19
Hydroptilidae		6	1	2								2
Isonychiidae												
Lepidostomatidae												
Leptoceridae									9			
Leptohiphidae												
Leptophlebiidae								1	4			
Leuctridae												
Linnephilidae			1	1		14			4			
Lymnaeidae				1							1	
Nemouridae												
Notonectidae												
Odontoceridae												
Oligochaeta		1	3			3	3		1			2
Palaemonidae												
Peltoperlidae												
Perlidae					2	5	3	1	15	13	1	
Philopotamidae						1	3		3	2		
Physidae												
Planorbidae		2	1	3								
Pleuroceridae												
Psephenidae								8	6	10	2	5
Rhyacophilidae												
Sialidae												
Simuliidae	3	41	8	9	198	1059	708	19	217	26	247	29
Sphaeriidae		1		1		1						
Stratiomyidae												
Tipulidae		4	7	10	1				3	2		3
Turbellaria	6	6	6	1	12	80	42	2				1
Unionidae												
Viviparidae										1		

Table A-1. Macroinvertebrate counts – contd.

Macroinvertebrate Name	MCG:3	MV1:1	MV1:2	MV1:3	MV2:2	MV2:3	SL1:1	SL1:2	SL1:3	SL2:1	SL2:2	SL2:3
Amphipoda					1							
Asellidae	8				11	12	254	273	1036	1080	678	466
Baetidae	179	1		1		3			4	1	8	5
Bithyniidae												
Blephariceridae												
Brachycentridae				2								
Caenidae									4			
Cambaridae	0	0	0			1	0			0		
Ceratopogonidae	1	2	1		6							
Chironomidae	128	77	134	73	617	377	227	293	231	231	261	364
Chloroperlidae												
Coenagrionidae												
Corbiculidae												
Corydalidae												
Culicidae	38		5	6	45	65	21	78	30	35	32	67
Dixidae												
Dytiscidae									7			
Elmidae	33		1	6			2	4	5		7	2
Emphididae					1							
Ephemerellidae							2					
Ephemeridae												
Ephyridae									6			
Glossomatidae						5						
Halipilidae				1					8	5	4	4
Helicopsychidae												
Heptageniidae						1						
Hirudinea			3	4	1	1			1		1	
Hydrachnida												
Hydrobiidae				1		1		1		47	5	13
Hydrophilidae				1								
Hydropsychidae	21	1				21			2			
Hydroptilidae					2							1
Isonychiidae												
Lepidostomatidae												
Leptoceridae												
Leptohyphidae												
Leptophlebiidae						1						
Leuctridae												
Linnephilidae												
Lymnaeidae												
Nemouridae												
Notonectidae					1							
Odontoceridae												
Oligochaeta	6	227	94	488	33	13	87	577	181	41	44	46
Palaemonidae												
Peltoperlidae												
Perlidae												
Philopotamidae	2								1			
Physidae					5	1						
Planorbidae	1		4	1	29	20	6	24	48	23	14	29
Pleuroceridae												
Psephenidae												
Rhyacophilidae												
Stalidae												1
Simuliidae	84	10	11	5	15	115	120	352	11	134	466	142
Sphaeriidae			6	1		3	2		3	10		1
Stratiomyidae				1								
Tipulidae	1	1	5		16	19						1
Turbellaria		134	9	34	44	13	46	49	77	54	54	43
Unionidae												
Viviparidae												

Table A-1. Macroinvertebrate counts – contd.

Macroinvertebrate Name	SL3a:1	SL3a:2	SL3a:3	SN2:1	TF3:1	TF3:2	TFN:1	TFN:2	TFN:3	TFW:1	TFW:2	TFW:3
Amphipoda												
Asellidae	27	90	140	1148	2685	1257	2601	339	2693	2	28	2
Baetidae	33	42	226		1							
Bithyniidae								1		1		
Blephariceridae												
Brachycentridae										1		
Caenidae												
Cambaridae	0			0	0					0		
Ceratopogonidae			1		6	2				2	1	
Chironomidae	384	1179	1777	19	107	128	10	7	1	47	23	17
Chloroperlidae												
Coenagrionidae			1									
Corbiculidae												
Corydalidae												
Culicidae	86	179	256	2	16	3	2		3		2	2
Dixidae												
Dytiscidae										2		
Elmidae	100	42	60	1	4		1			64	85	16
Emphididae												
Ephemerellidae			2									
Ephemeridae												
Ephydriidae												
Glossomatidae												
Halipilidae		4	1									
Helicopsychidae			1									
Heptageniidae		1										
Hirudinea						2						1
Hydrachnida			5		1	1						
Hydrobiidae			1		17	1	185	119	104		1	
Hydrophilidae										1		
Hydropsychidae	1	4	34	5	4	10	2	6		39	6	5
Hydroptilidae	1	3	15								1	
Isonychiidae												
Lepidostomatidae												1
Leptoceridae												
Leptohyphidae		2	1									
Leptophlebiidae												
Leuctridae												
Linnephilidae												
Lymnaeidae												
Nemouridae												
Notonectidae												
Odontoceridae												
Oligochaeta	2	86	88	2	9	1	11	48	10	28	126	27
Palaemonidae										3		2
Peltoperlidae												
Perlidae						1						
Philopotamidae		2	5							151		
Physidae						2		2	1	3	2	2
Planorbidae		11	5				6	3	13	2	2	1
Pleuroceridae						6						
Psephenidae	3		3									
Rhyacophilidae												
Sialidae												
Simuliidae	17	6	202	6	39	818	4		3	21	39	7
Sphaeriidae		1		1	6		6	4	1		1	
Stratiomyidae		1					1					
Tipulidae		3	14			1	3					
Turbellaria			10	1	138	21		2	13			5
Unionidae												
Viviparidae												

Table A-2: Macroinvertebrate indices for each site. Index calculation was based on feeding group assignment, taxa grouping, and HBI and VASCI formulas from Burton and Gerritsen (2003).

Site	Total Organisms	EPT	Total Taxa	HBI	VASCI	% EPT	%EPT less Hydropsychidae	% Scraper	% Filterer	% shredders	% insects	% Top 2 Dominant
CR1a:1	848	7	12	6.96	33.19	0.11	0.11	0.01	0.12	0.02	1.00	60.85
CR1a:2	773	7	12	6.72	28.41	0.14	0.14	0.02	0.00	0.02	1.00	89.78
CR1a:3	909	8	14	6.37	38.83	0.24	0.22	0.04	0.09	0.02	1.00	72.28
CR2:1	520	4	9	6.96	20.87	0.14	0.12	0.00	0.02	0.00	0.99	92.88
CR2:2	498	6	11	6.92	27.85	0.17	0.12	0.01	0.11	0.00	1.00	82.53
CR2:3	369	7	14	6.27	39.88	0.27	0.24	0.07	0.09	0.01	0.99	70.73
CR3:1	617	6	12	5.15	49.43	0.47	0.37	0.11	0.10	0.01	1.00	54.29
CR3:2	909	10	18	5.06	61.71	0.47	0.38	0.15	0.11	0.02	1.00	43.12
CR3:3	1111	8	17	5.59	49.49	0.39	0.31	0.08	0.12	0.03	1.00	59.14
CR4:1	551	10	20	4.70	68.69	0.51	0.45	0.25	0.08	0.04	0.98	37.39
CR4:2	731	10	21	5.69	62.32	0.39	0.25	0.16	0.25	0.01	0.89	41.45
CR4:3	699	9	19	5.27	55.81	0.42	0.26	0.14	0.18	0.11	0.99	50.64
CR6:1	1197	10	23	5.13	56.34	0.50	0.32	0.25	0.19	0.00	0.98	100.00
CR6:2	1177	8	23	5.59	57.22	0.44	0.27	0.20	0.20	0.00	0.99	56.41
CR6:3	866	8	21	5.36	56.76	0.71	0.38	0.07	0.35	0.01	0.98	63.74
CR7:1	318	8	21	4.67	66.56	0.48	0.36	0.35	0.12	0.04	0.95	53.14
CR7:2	1190	10	30	4.96	70.43	0.64	0.45	0.15	0.20	0.01	0.95	52.86
CR7:3	1362	9	24	4.59	69.47	0.59	0.42	0.29	0.18	0.02	0.98	58.66
CR8:1	486	9	19	4.67	66.28	0.64	0.38	0.27	0.26	0.02	0.96	50.62
CR8:2	622	10	26	4.80	75.50	0.62	0.39	0.29	0.23	0.02	0.97	27.65
CR8:3	454	9	19	5.08	63.38	0.71	0.37	0.17	0.37	0.02	0.98	53.08
CR9:1	1038	11	21	4.73	70.14	0.60	0.30	0.29	0.32	0.00	0.95	54.34
CR9:2	1248	10	21	5.29	62.39	0.54	0.28	0.20	0.28	0.02	1.00	48.64
CR9:3	1568	9	20	5.33	61.85	0.51	0.27	0.19	0.25	0.03	0.96	48.72
LN3:1	1341	3	11	6.12	29.11	0.01	0.00	0.01	0.01	0.00	1.00	97.69

Table A-2. Macroinvertebrate indices – contd.

Site	Total Organisms	EPT	Total Taxa	HBI	VASCI	% EPT	%EPT less Hydro.	% Scraper	% Filterer	% shredder	% insect	% Top 2 Dominant
LN3:2	348	2	9	6.62	28.12	0.03	0.00	0.01	0.05	0.00	0.87	85.34
LN3:3	265	2	12	7.67	31.24	0.03	0.02	0.04	0.06	0.01	0.66	58.87
LN4:1	480	4	13	7.53	48.04	0.03	0.03	0.09	0.00	0.00	0.14	7.50
LN4:2	3616	8	17	7.34	50.39	0.04	0.01	0.03	0.02	0.00	0.35	22.21
LW5:1	580	4	13	6.51	36.45	0.02	0.01	0.26	0.06	0.02	0.84	72.59
LW5:2	395	2	9	6.66	29.87	0.02	0.00	0.23	0.02	0.01	0.77	74.68
LW5:3	476	2	7	6.51	29.10	0.03	0.02	0.27	0.01	0.00	0.84	80.46
LW6:1	1094	5	17	7.23	37.75	0.04	0.02	0.08	0.09	0.00	0.73	51.01
LW6:2	1123	5	16	7.39	35.24	0.02	0.01	0.05	0.07	0.01	0.68	53.87
LW6:3	468	5	16	6.87	37.08	0.02	0.01	0.18	0.11	0.02	0.84	67.74
MC1:1	382	2	9	6.75	34.31	0.02	0.01	0.01	0.02	0.00	0.61	51.83
MC1:2	1595	5	15	6.36	35.76	0.04	0.02	0.01	0.03	0.01	0.86	80.69
MC1:3	1074	4	12	6.41	36.98	0.07	0.01	0.01	0.07	0.00	0.76	65.92
MC2:1	142	4	10	6.05	41.03	0.24	0.04	0.25	0.26	0.00	0.99	53.52
MC2:2	567	7	15	5.69	55.99	0.13	0.13	0.22	0.05	0.01	0.99	27.34
MC2:3	283	6	14	5.38	53.81	0.32	0.12	0.34	0.24	0.01	0.97	48.41
MCG:1	535	3	10	6.01	35.31	0.21	0.12	0.07	0.09	0.00	0.98	70.47
MCG:2	277	3	12	5.88	43.07	0.35	0.28	0.12	0.12	0.01	0.94	57.40
MCG:3	502	3	12	5.75	43.42	0.40	0.36	0.07	0.12	0.00	0.97	61.16
MV1:1	453	2	8	8.25	24.13	0.00	0.00	0.00	0.00	0.00	0.20	79.69
MV1:2	273	0	11	8.16	19.42	0.00	0.00	0.02	0.04	0.02	0.58	83.52
MV1:3	625	2	14	9.29	24.87	0.00	0.00	0.01	0.01	0.00	0.15	89.76
MV2:1	299	1	12	7.18	31.25	0.00	0.00	0.16	0.12	0.02	0.55	61.54
MV2:2	827	1	15	7.41	22.34	0.00	0.00	0.04	0.05	0.02	0.85	80.05
MV2:3	672	5	18	7.04	33.10	0.05	0.01	0.04	0.13	0.03	0.90	73.21
SL1:1	767	1	10	7.62	31.14	0.00	0.00	0.01	0.03	0.00	0.49	40.03

Table A-2. Macroinvertebrate indices – contd.

Site	Total Organisms	EPT	Total Taxa	HBI	VASCI	% EPT	%EPT less Hydropsychidae	% Scraper	% Filterer	% shredders	% insects	% Top 2 Dominant
SL1:2	1651	0	9	8.10	27.22	0.00	0.00	0.02	0.05	0.00	0.44	56.27
SL1:3	1655	4	17	7.96	37.25	0.01	0.01	0.03	0.02	0.00	0.19	76.56
SL2:1	1661	1	11	7.59	39.16	0.00	0.00	0.04	0.03	0.00	0.24	13.91
SL2:2	1574	1	12	7.25	28.88	0.01	0.01	0.02	0.02	0.00	0.49	72.68
SL2:3	1185	2	15	7.50	36.19	0.01	0.01	0.04	0.06	0.00	0.50	70.04
SL3a:1	654	3	10	6.82	29.72	0.05	0.05	0.16	0.13	0.00	0.96	74.01
SL3a:2	1656	6	17	7.50	29.42	0.03	0.03	0.03	0.11	0.00	0.89	82.00
SL3a:3	2848	7	22	7.11	38.25	0.10	0.09	0.03	0.10	0.01	0.91	71.38
SN2:1	1185	1	9	7.97	40.07	0.00	0.00	0.00	0.01	0.00	0.03	1.60
SN2:2	4686	3	12	7.97	26.74	0.01	0.00	0.00	0.01	0.00	0.01	98.66
TF3:1	3033	2	13	7.83	43.12	0.00	0.00	0.01	0.01	0.00	0.06	4.55
TF3:2	2254	2	15	7.20	39.36	0.00	0.00	0.00	0.01	0.00	0.43	36.29
TFN:1	2832	1	12	7.67	43.22	0.00	0.00	0.07	0.00	0.00	0.01	6.53
TFN:2	531	1	10	7.01	44.31	0.01	0.00	0.24	0.02	0.00	0.02	22.41
TFN:3	2842	0	10	7.81	40.62	0.00	0.00	0.04	0.00	0.00	0.00	3.66
TFW:1	367	3	15	4.92	58.74	0.52	0.41	0.19	0.11	0.00	0.89	58.58
TFW:2	317	2	13	7.37	39.20	0.02	0.00	0.29	0.03	0.00	0.50	66.56
TFW:3	88	2	13	7.23	39.49	0.07	0.01	0.22	0.08	0.01	0.55	50.00

Appendix B. RHA scores

Table B-1: RHA scores from Augusta and Rockingham Counties. RHA score assignment and calculation was based on Barbour et al. (1999).

Site	Cattle Classification	Epifaunal Substrate & Available cover	Embedded-ness	Velocity & Depth Regime	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles	Bank Stability	Vegetative Protection	Riparian Vegetative Zone	Total RHA Score
CR1a	Present	15	14	8	20	20	20	20	19	14	6	156
CR2	Present	16	7	10	20	20	20	19	20	20	4	156
CR3	Intermittent	10	11	3	20	20	20	13	17	20	2	136
CR4	No Cattle	11	12	8	20	20	20	20	20	20	4	155
CR6	Intermittent	11	11	3	20	20	14	16	20	20	2	137
CR7	No Cattle	17	18	9	20	20	20	15	20	20	15	174
CR8	Intermittent	18	16	8	20	20	20	20	18	19	10	169
CR9	No Cattle	20	13	7	20	20	20	17	19	20	14	170
LN3	Present	9	3	4	16	20	20	16	16	16	1	121
LN4a	No Cattle	18	16	10	19	20	20	16	20	20	18	177
LW5	No Cattle	15	14	13	20	20	20	16	18	20	6	162
LW6	No Cattle	11	13	11	20	20	20	11	20	20	4	150
MC1	No Cattle	20	18	11	16	19	20	16	17	18	16	171
MC2	No Cattle	18	15	10	20	20	19	13	18	16	15	164
MCG	No Cattle	5	5	6	18	20	19	8	19	14	5	119
MV1	Intermittent	18	13	8	20	20	20	20	18	18	4	159
MV2	Intermittent	18	17	12	20	20	20	15	20	20	16	178
SL1	No Cattle	7	3	3	20	20	13	6	20	20	0	112
SL3	No Cattle	16	14	7	20	20	20	19	16	18	3	153
SN2	Intermittent	6	7	2	18	20	15	4	20	20	4	116
TF3	Present	13	13	3	20	20	20	16	20	20	2	147

Table B-1: RHA scores – contd.

Site	Cattle Classification	Epifaunal Substrate & Available cover	Embedded-ness	Velocity & Depth Regime	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles	Bank Stability	Vegetative Protection	Riparian Vegetative Zone	Total RHA Score
TFN	No Cattle	3	8	3	20	18	13	5	18	18	4	110
TFW	No Cattle	13	18	3	20	19	15	16	20	20	4	148
Congers Creek at Bluff Rd	Present	11	5	8	18	20	18	16	20	14	7	137
Cooks Creek at Dayton between college St and 42	Present	13	13	12	15	19	15	17	16	10	0	130
Cub Run at Lawyer Rd. Next to 22	No Cattle	18	15	10	20	18	20	16	20	20	12	169
Cub Run at Penn Laird Rd	No Cattle	13	10	8	19	20	20	18	20	19	6	153
Cub Run at Power Dam Rd	No Cattle	6	9	1	20	8	20	8	20	20	19	131
Cub Run at Three Springs Rd	No Cattle	18	5	10	20	20	20	16	20	20	20	169
LN5	Present	11	9	11	20	18	20	18	16	17	1	141
LW at Brenneman Church Rd	No Cattle	18	10	18	20	20	20	20	18	19	19	182
LW2 at Grist Mill Rd	Present	13	13	10	20	20	20	15	15	14	4	144
Mill Creek at Port Republic Rd	Present	8	9	8	20	20	20	16	12	12	2	127
Mill Creek at Shady Grove Rd	Present	13	10	8	20	18	20	15	12	12	4	132
Muddy Creek at Bank Church Rd	Intermittent	16	12	10	17	20	20	8	20	19	18	160
Muddy Creek at Onyx Hill bridge	No Cattle	19	19	10	20	20	20	16	20	10	12	166
Muddy Creek at Rushville Rd	No Cattle	19	18	15	19	20	19	18	20	20	18	186
Muddy Creek below MC2	Present	8	8	9	20	20	16	19	12	16	0	128
SL Shank (below SL1)	Present	6	10	2	20	20	20	10	16	15	2	121

Appendix C

Water Quality Correlation Graphs

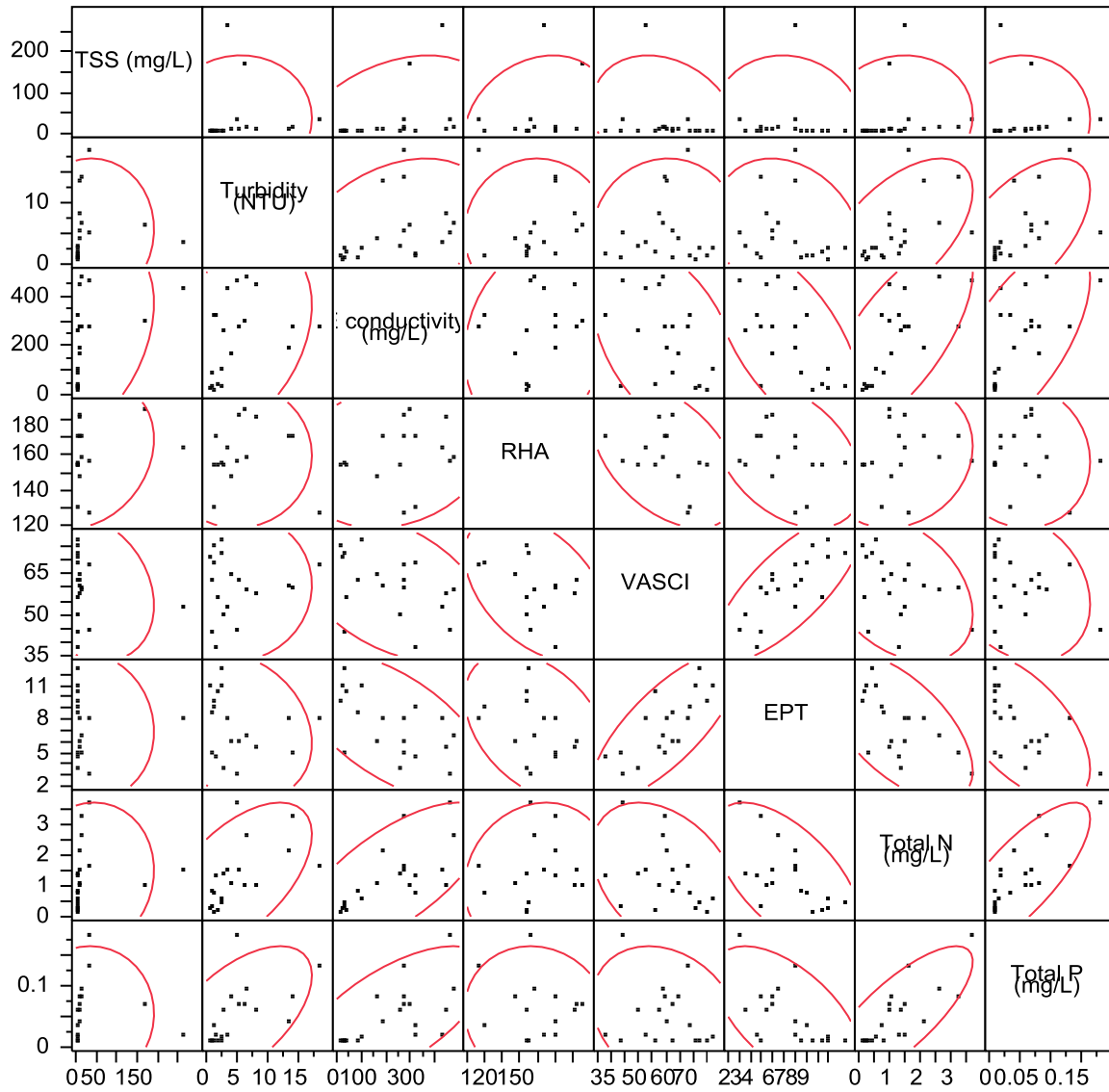


Figure C-1: Correlation of water quality parameters, EPT, and VASCI for the 20 ProbMon sample locations in the Shenandoah Valley, VA. Points are data values of each sample site; red lines are the 95% confidence limits.

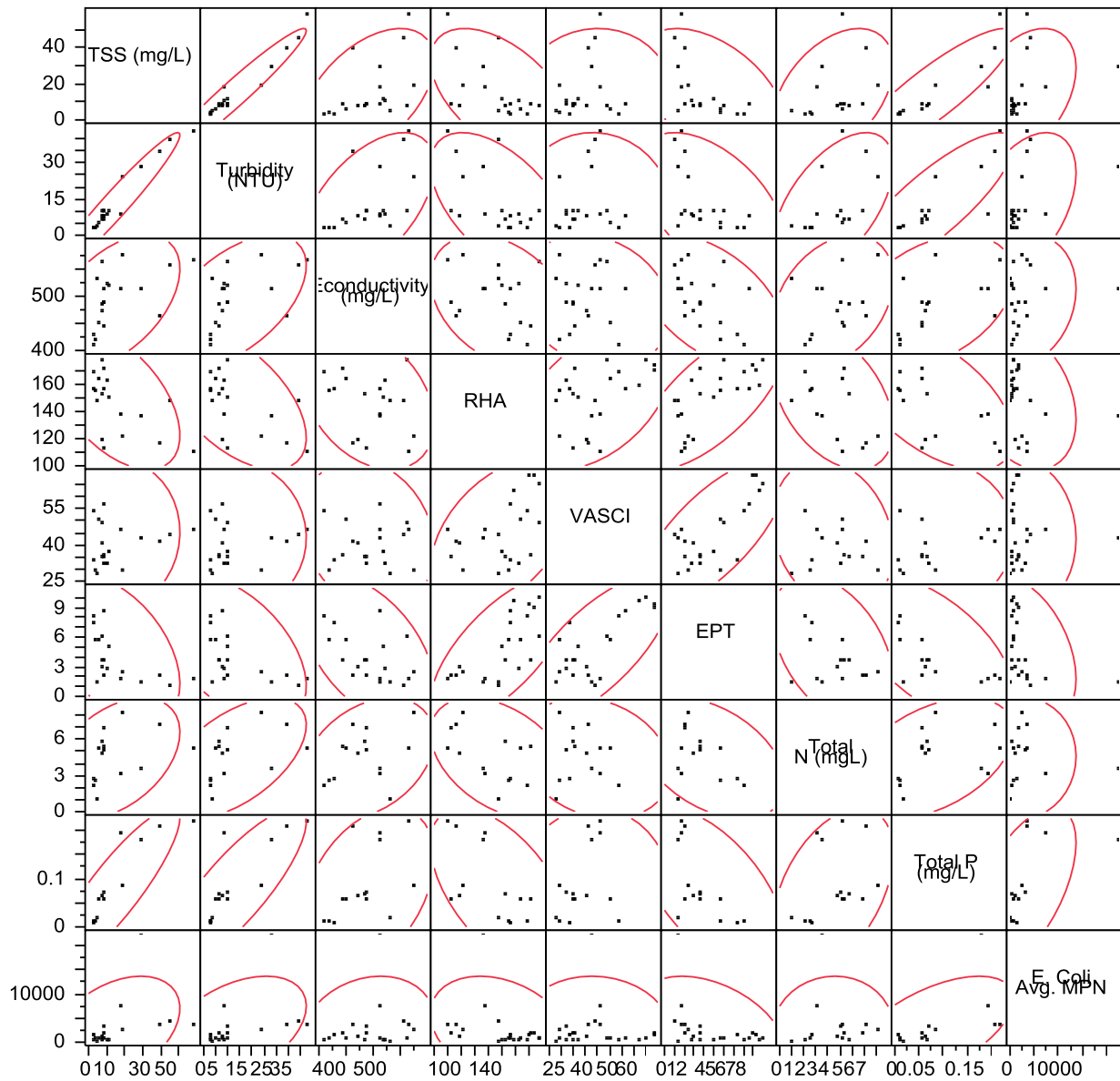


Figure C-2: Correlation of water quality parameters, EPT, and VASCI for the 24 sample locations in Rockingham County. Points are data values of each sample site; red lines are the 95% confidence limits.

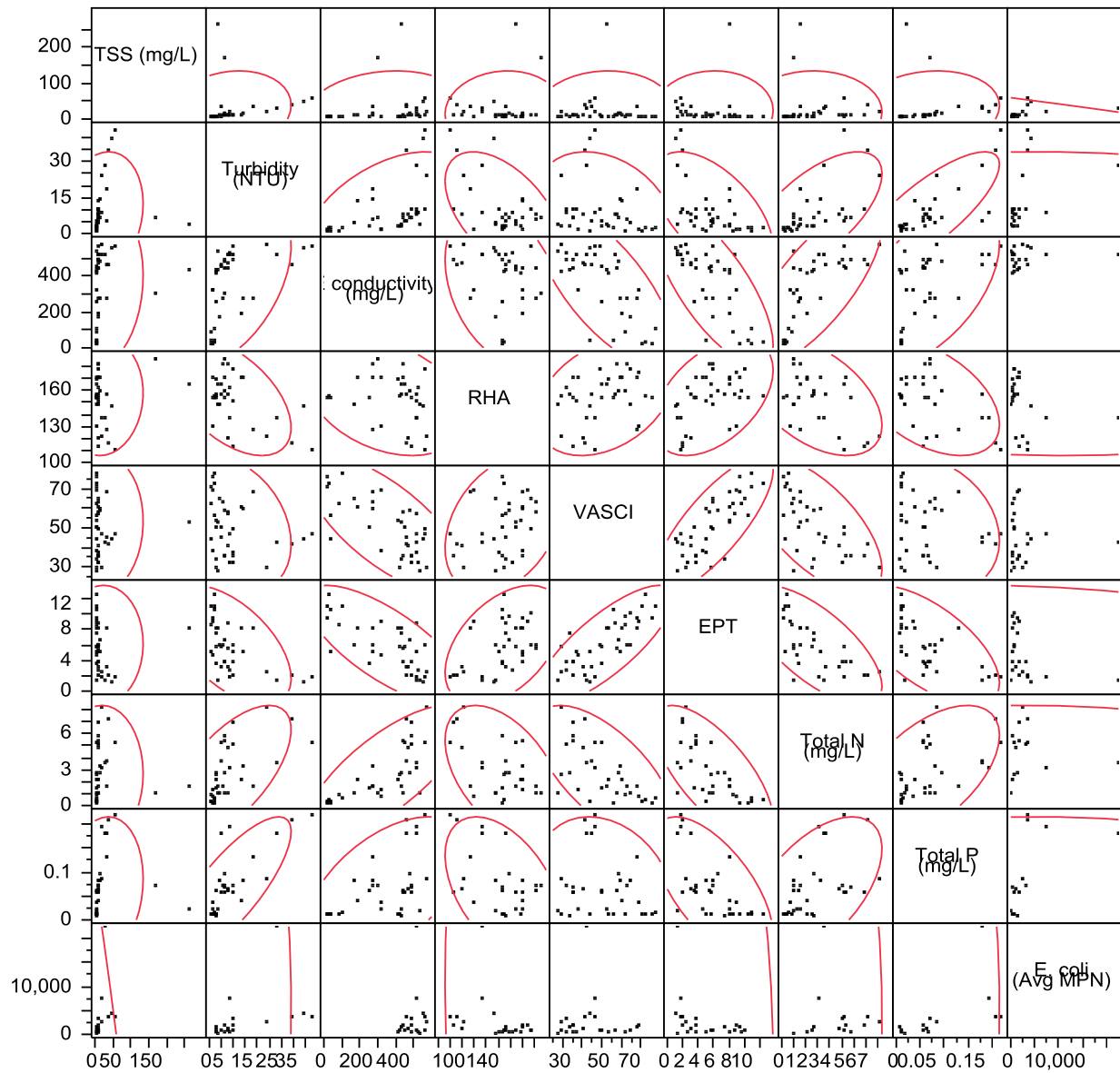


Figure C-3: Correlation of water quality parameters, EPT, and VASCI for all water quality data (44 locations including macroinvertebrate and ProbMon sites). Points are data values of each sample site; red lines are the 95% confidence limits.

Appendix D

Pictures from Longitudinal Studies



Figure D-1: Sampling point CR1a from longitudinal study CRa on Cub Run in Rockingham County, VA (looking upstream). Cattle had access to the stream directly above the sampling point, just across the fence.



Figure D-2: Sampling point CR2 from longitudinal study CRa on Cub Run in Rockingham County, VA (looking upstream). This point was below the CREP (Conservation Reserve Enhancement Program) fencing segment.



Figure D-3: Sampling point CR4 from longitudinal study CRb on Cub Run in Rockingham County, VA (looking upstream). This was the most downstream sampling point of the CRB longitudinal study. There was riparian tree cover on the right side of the stream.



Figure D-4: Sampling point MV2 from longitudinal study MV on Mountain Valley Tributary in Rockingham County, VA. There was top of bank fencing at this point. This was the most downstream sampling point of the MV longitudinal study. There was only one tree on this reach.



Figure D-5: Close up of sampling point MV2 from longitudinal study MV.



Figure D-6: Sampling point CR6 from longitudinal study CRb on Cub Run in Rockingham County, VA. This point was the most upstream sampling point of the CRb longitudinal study where cattle had access to the stream channel.



Figure D-7: Sampling point CR7 from longitudinal study CRb on Cub Run in Rockingham County, VA. This sampling point was along the cattle exclusion segment of the CRb longitudinal study. There was a significant riparian zone on both sides of the stream.



Figure D-8: Sampling point CR9 from longitudinal study CRb on Cub Run in Rockingham County, VA. This sampling point was along the cattle exclusion segment of the CRb longitudinal study at the most downstream sampling point of the reach.



Figure D-9: Sampling point SL1 from longitudinal study SL on Silver Creek in Rockingham County, VA. This photo shows the cattle-impacted stream segment.



Figure D-10: Sampling point SL2 from longitudinal study SL on Silver Creek in Rockingham County, VA. This sampling point was in the cattle exclusion segment of the stream. There is little tree cover along the reach.



Figure D-11: Sampling point SL3a from longitudinal study SL on Silver Creek in Rockingham County, VA. This point was in the cattle exclusion segment of the reach. It was the most downstream sampling point of the SL longitudinal study.