2006 NORTHEASTERN NATURALIST 13(2):269–286

Benthic Macroinvertebrate Fauna in Small Streams Used by Cattle in the Blue Ridge Mountains, Virginia

Amy Braccia[1,*] and J. Reese Voshell, Jr.[1]

Abstract - Cattle production is a common land use, and the adverse effects of cattle grazing on stream habitat and macroinvertebrates has been well documented. The purpose of our study was to provide a list of taxa that can be expected to occur in small streams impacted by cattle in the southern Blue Ridge Mountains and to demonstrate how taxon-specific natural history information can be used to gain insight about benthic habitat condition. We identified 97 benthic macroinvertebrate taxa from five cattle-impacted streams that differed in cattle grazing intensity. Our findings suggest that some macroinvertebrate taxa can sustain low levels of cattle grazing and that sedimentation is a major stressor to the macroinvertebrate fauna.

Introduction

Cattle production is a common use of land throughout the US. In the Blue Ridge Mountains, cattle are commonly raised in pastures where there are extensive lengths of first and second order streams. Cattle use these small streams year-round as a source of drinking water and during warm months as a place to cool themselves. Production of cattle in pastures with unrestricted access to the streams causes multiple changes to stream environments. Trampled stream banks cause increased erosion and sedimentation. Nutrient and organic loads increase from cattle urine and feces. Because of reduced trees and shrubs in the riparian zone, sunlight and water temperature increase, while inputs of coarse particulate organic matter decrease (Armour et al. 1991, Cooper 1993, Fleischner 1994, Kauffman and Krueger 1984, Owens et al. 1996, Trimble and Mendel 1995). These cattle-induced changes degrade water quality and habitat, which in turn alter the resident benthic macroinvertebrate fauna (Cook 2003, Dance and Hynes 1980, Delong and Brusven 1998, Harding et al. 1999, Scrimgeour and Kendall 2003, Strand and Merritt 1999, Wohl and Carline 1996).

Benthic macroinvertebrates, especially insects, are a diverse group of animals that are highly adapted to a wide range of natural conditions in freshwater environments. Nowhere is this more evident than in shallow, flowing water bodies, where the complex nature of fluvial geomorphology forms heterogeneous streambeds of unevenly distributed habitats. Benthic habitat consists of multiple variables, but water current, substrate, and food resources have been shown to be especially important in structuring macroinvertebrate assemblages at small spatial scales (Bouckaert and Davis

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[1] Department of Entomology, Virginia Tech, 300A Price Hall, Blacksburg, VA 24061; [*] Corresponding author - abraccia@vt.edu.

1998, Edington 1968, Egglishaw 1964, Eriksen 1968, Palmer et al. 2000, Rabeni and Minshall 1977, Reice 1980, Ulfstrand 1967). Substrate characteristics that influence macroinvertebrate microdistribution include mineral versus plant material, living versus decomposing plants, particle size of mineral substrate, food retention ability, heterogeneity, and stability (Allan 1975, Boyero 2003, Cobb et al. 1992, Cummins and Lauf 1969, DeMarch 1976, Erman and Erman 1984, Minshall and Minshall 1977, Trush 1979, Williams and Mundie 1978). For benthic macroinvertebrates, differences in assemblage structure often manifest themselves within 1 m, and sometimes within a few cm.

The wide range of natural habitat preferences and pollution tolerances among benthic macroinvertebrates makes them excellent organisms for freshwater bioassessment. Bioassessment is defined as an evaluation of the condition of a water body using biological surveys and other direct measurements of the resident biota in surface waters (Gibson et al. 1996). Bioassessments are usually done for regulatory purposes to determine if human activities have impaired a water body. Currently in the US, most states conduct the required bioassessments by means of the Rapid Bioassessment Protocols (RBPs) developed by the US Environmental Protection Agency (Barbour et al. 1999). Some important features of the RBPs include: qualitative sampling rather than a fixed area scheme, subsampling to manageable numbers (100–200 organisms), and data analysis based on metrics (= parameters) and multimetric indices (Voshell et al. 1997). These features make RBPs cost effective, but also result in the loss of taxon-specific ecological information, especially for rare taxa.

Rare taxa are a large component of the benthic macroinvertebrate fauna. They are often sensitive to changes in their environment and are usually among the first taxa to be eliminated following anthropogenic disturbance (Lenat and Resh 2001). However, the features of RBPs mentioned above are not conducive to the collection of rare taxa. Field ecologists have long recognized that the number of taxa, especially rare taxa, increase with sampling effort (see Vinson and Hawkins 1996). Furthermore, even if field and lab methods allow for the collection of rare taxa, information about these taxa is lost when taxonomic data are condensed into metrics, as recommended in RBPs.

In this study, we used extensive sampling, identification of all taxa to the lowest possible level of taxonomy, and taxon frequencies to describe changes in the benthic macroinvertebrate fauna that occurred along a predetermined gradient of habitat quality resulting from different levels of cattle grazing. The purpose of this study was to provide a record of taxa that can be expected to occur in small streams used for cattle production. In addition, we demonstrate how taxon-specific ecological information can be used to identify primary stressors in streams where there are multiple potential stressors to the benthic macroinvertebrate fauna.

Methods

Study sites and the habitat quality gradient

Five first-order stream reaches in the Little River drainage basin, Floyd County, VA, were selected as study sites. These study sites were selected because they were similar in size, gradient, underlying geology, and vegetative cover, and were subjected to a gradient of cattle grazing (Table 1). All of the streams originated in forested areas, and then flowed into pastures where the sampling reaches were located. The sampling reaches had no woody vegetation in the riparian area, and streambeds consisted mostly of mixes of cobble, pebble, and gravel. All study sites are within the Blue Ridge Interior Plateau ecoregion (Woods et al. 1996). Site 1 was recovering from cattle grazing (cattle were removed 12–15 years ago) and represented the best habitat quality. Cattle were rotationally grazed at Site 2 where there were 1.04 cattle per ha. Cattle had unlimited stream access at Sites 3, 4, and 5, where there were 1.54, 2.13, and 2.85 cattle per ha, respectively. Based on conversations with the private landowners, all pastures have been in operation for at least 50 years.

Prior to macroinvertebrate sampling, reach-scale habitat quality was determined at each study site following EPA's visually based RBP habitat assessment (Barbour et al. 1999). Following this methodology, stream reaches receive an overall habitat score based on stream reach features that include streambed characteristics, channel morphology, bank structure, and

Table 1. Cattle grazing gradient and physical characteristics of study sites in Floyd County, VA.

	Study sites				
	1	2	3	4	5
Grazing/habitat gradient					
Number of cattle per ha	0.00	1.04[A]	1.54	2.13	2.85
Percentage of bank exposed[B]	0	33	36	49	40
RBP habitat score[C]	155	142	117	111	113
Physical characteristics					
Watershed area (ha)	125	78	109	133	38
Elevation (m)	777	882	755	769	747
Reach slope (%)	3.5	4.3	3.3	3.5	4.1
Discharge range (L/sec)[D]					
Minimum	10	8	8	14	2
Maximum	62	47	25	77	10
Average	25	25	15	30	5
Mean wetted width (m)[E]	0.88	0.72	1.11	0.76	0.60
Mean depth (m)[E]	0.08	0.13	0.13	0.09	0.10

[A] Rotational grazing

[B] The percent of total stream length composed of bare soil was determined by direct measurement.

[C] RBP habitat scores and corresponding categories are as follows: optimal, 200–150; suboptimal, 149–100; marginal, 99–50; poor, 0–49.

[D] Baseflow discharge was measured on 8 separate occasions between July 2002 and August 2003.

[E] Wetted width and depth are averages of 12 transect measurements taken at each study reach during fall 2002 and spring 2003 (n = 24 at each study site).

the riparian zone. A stream could receive a habitat score ranging between 200, indicating the optimal condition, and 0, indicating the poorest habitat condition. Habitat scores indicated that our study sites represented a gradient of decreasing habitat quality (Table 1).

Benthic sampling

Benthic macroinvertebrate samples were taken in fall 2002 and late winter 2003. We used a stratified systematic sample design and restricted collections to three areas with the swiftest current at each study site. Current velocities within the sampling areas ranged from 0.01 to 0.74 m/s. Within each sampling area, we collected three or four benthic samples that were evenly spaced at least 2 m apart. This study design resulted in the collection of 115 benthic samples; fifty-nine samples were collected in fall 2002, and 56 samples were collected in late winter 2003.

Benthic macroinvertebrates were collected by inserting a modified stovepipe sampler (0.30-m diameter) approximately 10 cm into streambed substrates. All material within the core was removed with the aid of a hand pump, placed in plastic bags, preserved with ethanol, and transported to the lab for analysis. In the lab, benthic samples were rinsed through a 250-μm sieve, and macroinvertebrates were hand sorted from stream material under a dissecting microscope, enumerated, and identified to the lowest possible taxonomic level. Most insect taxa were identified to genus; other invertebrate taxa were identified to class, order, or family.

Data analysis

The frequency of occurrence of each taxon was reported for each study site. Frequencies were obtained by summing the total number of samples in which the taxon occurred and dividing by the total number of samples collected at the study site. Each taxon was assigned a pollution tolerance value (PTV), functional feeding group (FFG; a mode of acquiring food based on morphology and behavior), and habit (a mode of existence or how the organism maintains its position in its environment). Assignments to these categories were made based on published literature (e.g., Barbour et al. 1999, Brigham et al. 1982) and the professional judgment of experienced entomologists. PTVs are commonly reported on a scale of 0 to 10, with 0 indicating very sensitive and 10 indicating very tolerant. In this study, taxa with PTVs of 0–2 were considered sensitive while taxa with PTVs of 8–10 were considered tolerant. Taxa that occurred in less than 5% of all samples were categorized as rare; all other taxa were considered to be common.

Results

Ninety-seven taxa were identified during this study (Appendix 1). The total numbers of taxa at each study site were 68, 75, 69, 51, and 46 at Sites 1, 2, 3, 4, and 5, respectively. The rotational grazing site (Site 2) supported the most taxa, while the study sites with the most degraded habitat (Sites 4 and 5) had the fewest taxa. The majority (86%) of taxa were insects, which were represented by six orders. Diptera and Trichoptera had the greatest taxa richness with 27 and 18 taxa, respectively. Taxa richness was similar among the Ephemeroptera, Plecoptera, and Coleoptera with 10, 10, and 11 taxa, respectively. The Odonata were represented by four taxa.

We identified 45 taxa that clearly declined in frequency or became absent along the gradient of cattle grazing. These included Ancylidae, Hydracarina, *Baetis*, *Baetisca, Ephemera*, *Ephemerella*, *Eurylophella*, *Serratella, Stenonema, Habrophlebia vibrans, Paraleptophlebia, Cordulegaster, Gomphus*, *Lanthus*, *Allocapnia*, *Suwallia, Sweltsa*, *Leuctra*, *Amphinemura*, *Tallaperla*, *Acroneuria, Isoperla*, *Remenus bilobatus*, *Yugus*, *Diplectrona, Lepidostoma, Setodes, Pycnopsyche, Psilotreta*, *Wormaldia*, *Polycentropus*, *Lype diversa, Rhyacophila, Helichus*, *Optioservus, Oulimnius latiusculus*, *Promoresia*, *Stenelmis*, *Psephenus herricki, Anchytarsus,* Ceratopogonidae, *Oreogeton*, *Antocha*, *Dicranota*, and *Hexatoma* (see Appendix 1 for higher taxonomic classification categories). Conversely, 11 taxa increased in frequency along the gradient and included: *Gammarus*, *Corbicula fluminea*, Sphaeriidae, *Oligostomis*, *Ptilostomis*, Ephydridae, *Limnophora, Pericoma, Psychoda*, *Eristalis*, and *Tipula.*

Taxa that showed no clear response to the gradient consisted of the non-insect taxa Planariidae, Nematoda, Oligochaeta, Cambaridae, Copepoda, and Pleuroceridae, and the insect taxa *Epeorus*, *Nigronia fasciatus*, *Glossosoma nigrior*, *Goera*, *Agarodes*, *Neophylax*, *Ectopria*, Chironomidae, *Hemerodromia, Simulium*, *Prosimulium*, *Chrysops*, and *Pseudolimnophila.*

Thirty-one of the taxa (32%) encountered during this study were pollution sensitive. The total number of pollution-sensitive taxa at each study site declined along the gradient; there were 25, 26, 20, 17, and 13 sensitive taxa at Sites 1, 2, 3, 4, and 5, respectively. Twenty-two pollution-sensitive taxa (*Ephemerella*, *Serratella*, *Habrophlebia vibrans*, *Paraleptophlebia*, *Lanthus*, *Allocapnia*, *Suwallia*, *Sweltsa*, *Leuctra*, *Tallaperla*, *Acroneuria*, *Isoperla*, *Remenus bilobatus*, *Yugus*, *Diplectrona*, *Lepidostoma*, *Setodes*, *Psilotreta*, *Wormaldia*, *Rhyacophila*, *Oulimnius latiusculus*, and *Promoresia*) declined along the grazing gradient, while 10 pollution-sensitive taxa (Pleuroceridae, *Epeorus*, *Stylogomphus albistylus*, *Glossosoma nigrior*, *Goera*, *Oligostomis*, *Agarodes*, *Fattigia pele*, *Neophylax*, and *Blepharicera*) showed no response to the gradient. One pollution-sensitive taxon, *Oligostomis*, increased along the gradient. We encountered 11 pollution-tolerant taxa (Planariidae, Muscidae, Nematoda, Oligochaeta, Hirudinea, Lymnaeidae, Sphaeriidae, *Limnophora*, *Pericoma*, *Psychoda*, and *Eristalis*), and the total number of pollution-tolerant taxa at each study site did not show a clear response to the gradient. There were 5, 8, 10, 7, and 8 tolerant taxa at Sites 1, 2, 3, 4, and 5, respectively.

Discussion

Taxa list

We have recorded a fairly long list of taxa that exist in five small streams where cattle currently have direct access to the channel or where there is a history of using the streams for cattle production (Appendix 1). It should be noted that our list would probably be much longer if all of the immature specimens could be identified to species. The high number of taxa that we report is also noteworthy because none of the streams are in pristine ecological condition. Even at Site 1, where there are no cattle grazing at the present time, the stream flows through land that was cleared of all trees and converted to agricultural use at least 50 years ago and was subjected to cattle grazing until 12–15 years ago. The habitat score of 155 at Site 1 is barely in the upper quartile of possible scores (151–200), which is considered to be representative of optimal conditions. However, we found 68 taxa at Site 1, with more than one-third of them (37%) considered to be sensitive to pollution or other environmental stress.

Agriculture, specifically livestock grazing, is recognized to cause degraded water quality and habitat conditions, which lead to reduced biodiversity of macroinvertebrates. However, in our study, the highest number of taxa, 75 out of 97, occurred at the site with light rotational grazing (Site 2). Of the 75 taxa, 26 (33%) are considered to be sensitive taxa. The habitat score of 142 at Site 2 was at the upper end of the third quartile (101–150), which is considered to be representative of suboptimal conditions that are still satisfactory and nearly as good as Site 1. These findings suggest that in some stream settings, habitat quality and benthic macroinvertebrate biodiversity can be sustained at low levels of grazing.

Where grazing pressure increased to 40 cattle present all of the time (Site 3), the habitat score dropped considerably, to 117. Although we found 69 taxa at Site 3, there were fewer sensitive ones (20 taxa or 29%). Even where grazing intensity was high at Sites 4 and 5, the benthic macroinvertebrate fauna was not completely decimated. Habitat scores did not drop much lower, and a moderate number of taxa, including some sensitive taxa, still occurred, although at lower frequencies. The complex nature of fluvial geomorphology probably allows for the presence of infrequent patches of suitable habitat for some sensitive taxa, even in the most degraded streams. This is useful information for predicting stream recovery. If cattle are excluded from streams, such as at Site 1, or they are given limited access to streams, such as at Site 2, the infrequent patches of suitable habitat will serve as sources for colonization by sensitive macroinvertebrates. Successional recovery can be expected to take place, including restoration of habitat quality and macroinvertebrate biodiversity.

The above information is not meant to suggest that cattle grazing does not negatively affect the ecological condition of small streams, especially when higher densities of cattle have unrestricted access to the stream channel. For example, at Sites 4 and 5, there were appreciably fewer taxa. The second purpose of this research was to determine if compiling an extensive list of the taxa occurring in the streams and examining the natural history of those macroinvertebrates could explain which of the specific stressors from cattle grazing are most responsible for differences in the fauna.

Stressor identification

Cattle urine, either through direct inputs to water or leaching from pasture, is a source of inorganic nutrients to streams. Excessive nutrient loads stimulate primary production causing streambeds to become covered with algae, especially cyanobacteria. Organic loads, in the form of manure, can also be excessive in livestock-impacted streams. Nutrients and dissolved organic compounds from organic loading cause the growth of various microorganisms, especially fungus, on benthic substrate and biota (Hynes 1971, Mason 1996). Excessive algal growth and fungus on streambeds eliminates physical habitat for taxa that need clean substrates for attachment, such as clingers. During the decomposition of excessive algae and organic matter, oxygen is consumed by heterotrophic organisms. Ultimately dissolved oxygen concentrations are lowered for benthic macroinvertebrates. Oxygen-sensitive macroinvertebrate taxa, such as mayflies and stoneflies, become absent while taxa more tolerant of low dissolved oxygen (e.g., *Eristalis*, *Psychoda*) persist. Furthermore, when fungus colonizes macroinvertebrate bodies and gills, taxa cannot obtain their oxygen requirements. Lemly (1998) attributed increased macroinvertebrate mortality to attached fungus in Appalachian streams that received pasture runoff.

Altered temperature regime is another possible stressor to the macroinvertebrate fauna in cattle-impacted streams. Trees and shrubs are often reduced along streams in agricultural settings, especially in pasture streams. The resulting lack of shade causes warmer, more variable water temperatures and taxa that have narrow temperature requirements, especially stoneflies, are often eliminated.

Dissolved oxygen, water temperature, and nutrients vary over larger spatial scales and are not expected to change within stream reaches with similar riparian characteristics (Vannote et al. 1980, Wetzel 2001). Thus, we expected the absence of cold-adapted, oxygen-sensitive, and clinging-scraping taxa at the most degraded study sites if these are the major stressors from cattle grazing; however, this was not the case. We encountered taxa with narrow temperature requirements and high oxygen requirements, such as mayflies and stoneflies, as well as sensitive clinging-scraping taxa, such as Pleuroceridae, *Glossosoma nigrior*, *Goera*, *Psilotreta*, *Neophylax*, *Oulimnius latiusculus*, *Promoresia*, and *Blepharicera*, at the most degraded sites. Although temperature and dissolved oxygen measures were not recorded, the presence of these taxa at the most degraded study sites suggested that temperature alterations, decreased dissolved oxygen, and habitat alterations associated with nutrient and organic loading were unlikely the major stressors to the macroinvertebrate fauna in these streams.

Cattle-impacted streams often have unstable, trampled stream banks, which become significant sources of inorganic sediments when they erode. When bedload sediments are excessive, the undersides of cobble and streambed interstices become embedded and clogged with fine sand and silt; clean, interstitial patches are less frequent while the frequency of sand and silt patches increases. These benthic habitat alterations have been shown to alter macroinvertebrate fauna and displace taxa that crawl among streambed interstices (Chutter 1969, Cordone and Kelley 1961, Lenat 1984, Lenat et al. 1981, Wood and Armitage 1997).

Many of the taxa that declined in frequency, or became absent along the grazing gradient, crawl among interstitial spaces formed from mixes of cobble and pebble (often called rubble) and coarse gravel, the undersides of cobble, and hyporheic zones (Godbout and Hynes 1982; Hynes 1970, 1974; Mackay 1969; Pennak and Van Gerpen 1947; Percival and Whitehead 1929; Sprules 1947; Ward 1975; Williams and Hynes 1974). For example, during daylight hours, several interstitial taxa, including *Baetis* spp. and *Ephemerella* spp., occur on the undersides of stones but migrate to stone surfaces at night to avoid visual predators such as fish (Elliott 1968). Late instar caddisflies, including *Psilotreta*, *Pycnopsyche* spp., and *Rhyacophila*, attach to the undersides of stones or burrow into coarse gravel prior to pupation (Anderson 1967, Lloyd 1921, Mackay and Wiggins 1979). Stoneflies are particularly selective in their substrate choices; Harper and Hynes (1970) found the winter stoneflies, *Allocapnia* and *Taeniopteryx,* in diapause at depths as far as 10 to 20 cm beneath a streambed in Canada. Diapause is a genetically encoded state of arrested development that likely evolved so that cold-adapted stoneflies can avoid high summer temperatures and drought. We attribute the decreased frequencies of crawling taxa (100%, 100%, 100%, 71%, and 79% occurrence of crawling taxa at Sites 1, 2, 3, 4, and 5, respectively) to physical habitat alteration, i.e., clogged streambed pore space, as a result of excessive sediments.

Further evidence for alterations to the physical nature of the streambed were increased frequencies and occurrences of soft-bodied taxa that are adapted for burrowing into soft streambed substrates along the grazing gradient. The majority of taxa that responded positively to the grazing gradient, such as *Corbicula fluminea*, Sphaeriidae, Ephydridae, *Limnophora*, *Pericoma*, *Psychoda*, *Eristalis*, and *Tipula*, burrow into or sprawl on substrate composed of densely packed sand and silt, or organic matter, such as detritus, cattle manure, or decaying vegetation. For example, the rat-tailed maggot, *Eristalis*, burrows into soft substrates and is morphologically adapted to exist in environments devoid of oxygen, such as sewage lagoons, because it obtains atmospheric oxygen by means of a long, retractable breathing tube. The occurrence of this rare taxon at Site 3 suggests that patches of manure or decaying vegetation were present but infrequent. *Psychoda* and *Pericoma* occur most frequently in household and sewage drainpipes and are typically not abundant in streams. When they do occur in streams, they burrow into soft sediments and collect fine organic matter for food (collector-gatherers). Increased frequencies of *Psychoda* and *Pericoma*, and the presence of the rare taxon *Eristalis* at Site 3, imply that habitat patches composed of fine sediments enriched with organic matter increased along the grazing gradient. Further evidence that organic matter changed along the gradient, was the occurrence of phryganeid caddisflies at the most degraded study sites. Phryganeid caddisflies (*Oligostomis* and *Ptilostomis*) are often associated with aquatic vascular plants and accumulations of coarse detritus because of their food (shredders) and case-building requirements. When cattle trample the margins of small streams, the channels become braided with small hummocks of pasture grasses. The hummocks, and their associated grasses, provide ideal habitat for taxa such as phryganeid caddisflies. We attribute the presence and increased frequency of *Oligostomis*, *Ptilostomis*, *Eristalis*, *Pericoma*, and *Psychoda* to elevated benthic organic loads in the form of cow patties, pasture vegetation, and vegetation hummocks.

It is noteworthy that several sensitive taxa that did not respond to the grazing gradient, particularly *Glossosoma nigrior*, *Goera*, *Neophylax*, and *Blepharicera*, are clingers that are associated with the exposed surfaces of stable rocks. These taxa have rarely been reported from the undersides of substrates (Frutiger 2002, Kovalak 1976, Scott 1958). Clinging taxa are morphologically or behaviorally adapted to exist on the surface of clean, stable substrate in swift water where they scrape hard surfaces for food (scrapers). For instance, the net-winged midge, *Blepharicera*, maintains its position in swift, shallow current by clinging to clean, stable substrate by means of a row of suction discs on its ventral side. The caddisflies, *Neophylax* and *Goera*, are able to exist on the current-exposed side of stable rocks with the aid of portable cases formed from rock fragments. Their case-making behavior is unique among the Trichoptera because the larvae attach ballast stones on the sides of the case to help anchor the larvae in swift current. It is possible that these clinging taxa are able to persist because the surfaces of rock and cobble in the swift currents were not altered by sedimentation.

Implications for management and monitoring

Considering the presence or absence of individual taxa in conjunction with taxon-specific natural history provides a great deal of useful information about the ecological condition of water bodies and probable causes of impairment. The absence and decreased frequency of taxa that require clean streambeds along the grazing gradient led us to conclude that excessive sedimentation was the major stressor to the benthic macroinvertebrate assemblage. It is questionable whether we would have reached the same conclusions and findings if we used less rigorous field sampling methods with subsampling (the RBP approach). With limited field sampling, it is unlikely that the rare taxa *Glossosoma nigrior*, *Oligostomis*, *Ptilostomis*, *Blepharicera*, and *Eristalis*, all of which provided useful information about habitat, would have been encountered. Furthermore, if rare taxa had been collected, they would have been lost if our data were condensed into metrics. Recent studies have shown that taxonomic determinations beyond family, and the inclusion of rare taxa, provide further insight into the status of water quality and may be necessary to determine specific stressors (Nijboer and Schmidt-Kloiber 2004, Waite et al. 2004).

In summary, increased sampling effort resulted in the collection of a rich macroinvertebrate fauna that provided a large amount of ecological information. We did not rely on rigorous statistical methods to: (1) determine that the primary stressor to the macroinvertebrate fauna is likely sediment from eroded stream banks, and (2) that low to moderate cattle grazing around these small streams does not deteriorate the macroinvertebrate fauna relative to recovery conditions.

Acknowledgments

We thank all of the private landowners for their hospitality, and we are especially grateful to Kathy Hanna, Stephen Hiner, Trisha Voshell, Rachel Wade, and Hillery Warner for their assistance in the field and laboratory. The senior author was supported by a US Department of Agriculture, Food and Agricultural Sciences National Needs Graduate Fellowship. The Department of Entomology and the Virginia Agricultural Experiment Station at Virginia Tech provided further support.

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Appendix 1. Taxon frequencies, reported as a percent, at each study site. superscipt R = rare; PTV = pollution tolerance value (S = pollution sensitive, T = pollution tolerant); FFG = functional feeding group (CG = collector-gatherer, PR = predator, GN = generalist, SC = scraper, CF = collector-filterer, SH = shredder); Habit (SP = sprawler, BU = burrower, CR = crawler, CL = clinger, CI = climber).

				Study sites				
				Site 1	Site 2	Site 3	Site 4	Site 5
	PTV	FFG	Habit	n = 24	n = 23	n = 23	n = 22	n = 23
NON-INSECTA								
Planariidae	T	CG	SP	21	13	57	23	22
Nematoda	T	CG	BU	63	78	74	50	61
Oligochaeta	T	CG	BU	100	100	96	95	100
Hirudinea^R	T	PR	SP			9		
Copepoda		-	-	83	91	74	64	78
Amphipoda								
Gammaridae								
Gammarus^R		CG	CR			4		9
Decapoda								
Cambaridae		GN	GN	21	9	17	9	13
Gastropoda								
Ancylidae			SC	CL	4	83		
Lymnaeidae^R	T	CG	GN	4		4		
Planorbidae^R			CG	SP		9		
Pleuroceridae	S	SC	CL	100	100	78	100	39
Bivalvia								
Corbiculidae								
Corbicula fluminea (Müller)^R		CF	BU		13	4		4
Sphaeriidae	T	CF	BU	63	74	91	73	70
Hydracarina		PR	CR	88	91	96	41	52
INSECTA								
Ephemeroptera								
Baetidae								
Baetis		CG	CL	33	39	39	5	17
Baetiscidae								
Baetisca		CG	SP	4	17	13		

	PTV	FFG	Habit	Site 1 n = 24	Site 2 n = 23	Site 3 n = 23	Site 4 n = 22	Site 5 n = 23
Ephemeridae								
Ephemera^{R}		CG	BU		4			
Ephemerellidae								
Ephemerella	S	CG	CR	46	57	48	27	22
Eurylophella		CG	CR	42	52	70	18	
Serratella^{R,}	S	CG	CR		4			
Heptageniidae								
Epeorus	S	CG	CL	25	17		14	4
Stenonema		SC	CL	42	39	17		
Leptophlebiidae								
Habrophlebia vibrans Needham^{R}	S	CG	CR		4	4		
Paraleptophlebia^{S} S		CG	CR	83	70	30	5	
Odonata								
Cordulegastridae								
Cordulegaster^{R}		PR	BU	4				
Gomphidae								
Gomphus^{R}		PR	BU	4	4	9		
Lanthus	S	PR	BU	33	26			9
Stylogomphus albistylus (Hagen)^{R}		PR	BU	4		4		
Plecoptera								
Capniidae								
Allocapnia	S	SH	CR	75	74	43	18	39
Chloroperlidae								
Suwallia	S	PR	CR	33	48	35		9
Sweltsa^{R}	S	PR	CR	4				
Leuctridae								
Leuctra	S	SH	CR	71	83	43	14	22
Nemouridae								
Amphinemura		SH	CR	25	17	9	5	13
Peltoperlidae								
Tallaperla	S	SH	CR	42	30	9		9

	PTV	FFG	Habit	Site 1 n = 24	Site 2 n = 23	Site 3 n = 23	Site 4 n = 22	Site 5 n = 23
Perlidae *Acroneuria*^{R}	S	PR	CR	8	4			
Perlodidae								
Isoperla	S	PR	CR	42	61	35	9	26
Remenus bilobatus (Needham & Claassen)^{R}	S	PR	CR	8				
Yugus^{R}	S	PR	CR	4				
Taeniopterygidae								
Taeniopteryx^{R}		SH	CR	4				4
Megaloptera								
Corydalidae								
Nigronia fasciatus (Walker)^{R}		PR	CR	4			5	
Trichoptera								
Glossosomatidae								
Glossosoma nigrior Banks^{R}	S	SC	CL		9		5	
Hydropsychidae								
Diplectrona	S	CF	CL	42	83	30	9	4
Hydropsyche		CF	CL		17	65		9
Lepidostomatidae								
Lepidostoma	S	SH	CR	13	48	9		
Leptoceridae								
Oecetis^{R}		PR	CR		4	4		
Setodes	S	CG	CR	29	4	9		
Limnephilidae								
Goera	S	SC	CR	13	17	65	9	
Pycnopsyche		SH	CR	13	9			4
Odontoceridae								
Psilotreta	S	SC	CL	63	22	22	5	
Philopotamidae								
Chimarra^{R}		CF	CL			9		
Wormaldia^{R}	S	CF	CL	4	9			
Phryganeidae								
Oligostomis^{R}	S	PR	CI			17	5	
Ptilostomis^{R}		SH	CI		4	9	9	

	PTV	FFG	Habit	Site 1 n = 24	Site 2 n = 23	Site 3 n = 23	Site 4 n = 22	Site 5 n = 23
Polycentropodidae								
Polycentropus^{R}		PR	CL	8				
Psychomyiidae								
Lype diversa (Banks)		SC	CL	13	13	4		
Rhyacophilidae								
Rhyacophila	S	PR	CR	21	26	9		4
Sericostomatidae								
Agarodes	S	SH	SP	4	26	65	5	
Fattigia pele^{R}	S	SH	SP		4			
Uenoidae								
Neophylax	S	SC	CL	13	9	17	9	9
Coleoptera								
Dryopidae								
Helichus^{R}		SC	CL	4				
Dytiscidae^{R}		PR	GN			9		
Elmidae								
Dubiraphia^{R}		SC	CL			4		
Optioservus		SC	CL	83	83	52	9	
Oulimnius latiusculus (LeConte)	S	SC	CL	88	100	87	27	22
Promoresia	S	SC	CL	21	39	9	9	
Stenelmis		SC	CL	29	9	35		
Hydrophilidae								
Tropisternus^{R}		PR	GN	4	9	9		
Psephenidae								
Psephenus herricki (DeKay)		SC	CL	29	4	43		
Ectopria		SC	CL	88	43	4	23	
Ptilodactylidae								
Anchytarsus		SH	CL	29	39	22		
Diptera								
Blephariceridae								
Blepharicera^{R}	S	SC	CL					23

	PTV	FFG	Habit	Site 1 n = 24	Site 2 n = 23	Site 3 n = 23	Site 4 n = 22	Site 5 n = 23
Ceratopogonidae		-	-	100	100	91	73	83
Chironomidae		-	-	100	100	100	100	100
Dixidae								
Dixa^{R}		CG	CR	8	4			9
Dolichopodidae^{R}		PR	SP	4	9			4
Empididae								
Hemerodromia		PR	CR	21	22	83	18	13
Oreogeton^{R}		PR	SP		9			
Ephydridae		CG	SP		9	22	18	13
Muscidae^{R}	T	PR	SP		13	4		4
Limnophora	T	PR	BU		4	4	23	22
Psychodidae								
Pericoma	T	CG	BU		26	17	27	57
Psychoda	T	CG	BU		4		36	22
Ptychopteridae								
Bittacomorpha^{R}		CG	BU			9		
Simuliidae								
Simulium		CF	CL	42	70	74	64	57
Prosimulium		CF	CL	17	35		14	30
Syrphidae								
Eristalis^{R}	T					4		
Tabanidae								
Chrysops		CG	BU	25	57	43	9	22
Tipulidae								
Antocha		CG	CL	79	91	43	32	4
Dicranota		PR	CR	38	48		9	9
Hexatoma		PR	CR	67	78	61	9	17
Molophilus		CG	BU	4	13	13	9	22
Ormosia		CG	BU	4	13	17		4
Pedicia		PR	BU			4		
Pilaria^{R}		PR	BU					4
Pseudolimnophila		PR	BU	17	4	39		26
Rhabdomastix^{R}		-	-		9	4		4
Tipula		SH	BU	8	57	26	41	48