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Livestock exclusion influences on riparian vegetation, channel morphology, and benthic macroinvertebrate assemblages

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Abstract: Measurements in paired stream reaches with and without livestock access in southwestern Virginia suggest that livestock exclusion practices installed on short, isolated stream reaches result in improved geomorphic and riparian vegetation conditions, but do not significantly improve benthic macroinvertebrate assemblages. Numerous state and federal programs encourage agricultural producers to protect environmentally sensitive lands (such as streams and wetlands) through the elimination of livestock access to these sensitive areas. In addition to achieving soil conservation goals, it is widely believed that livestock exclusion from streams will result in improvements in riparian vegetation, channel morphology, as well as instream habitat and aquatic insect assemblages. This research assessed the changes in channel morphology, riparian vegetation, and benthic macroinvertebrate assemblages as affected by livestock exclusion over time. Study sites consisted of paired, nearly contiguous stream reaches (five pairs), with and without active livestock access, across a range of time since livestock exclusion was implemented. Four of the livestock exclusion reaches ranged in time since best management practice implementation from 1 to 14 years, while one site consisted of a grazed reach paired with a reach that has been forested and without cattle access for at least 50 years. Livestock exclusion reaches were significantly deeper, had larger median riffle substrate, and scored higher on the Reach Condition Index (a qualitative geomorphic assessment methodology). The livestock exclusion reaches also had significantly higher riparian groundcover vegetation biomass; however, the benthic macroinvertebrate assemblages were not significantly different. The only parameter that showed correlation with time since livestock exclusion was the Reach Condition Index, which increased (indicating improved bank stability) with time since livestock exclusion. Our observations suggest that, while livestock exclusion from streams has positive impacts on streams, best management practice implementation along short stream stretches does not have the desired instream benefits. In particular, benthic macroinvertebrate response depends more on upstream watershed-scale conditions and impacts than localized, reach-scale livestock-access issues. Therefore, a more targeted approach addressing entire stream lengths and the associated watersheds may be required to restore the integrity of aquatic ecosystems.

Key words: benthic macroinvertebrates—channel morphology—livestock exclusion—riparian buffers

Many streams in the United States experience severe bank retreat and habitat destruction resulting from livestock access (Rickard and Cushing 1982; Stuber 1985; Brown 2003; VDCR 2006). Unrestricted stream access results in frequent defecation in and near the water, a decrease in riparian vegetation diversity and density, and weakened streambanks that are highly erodible and physically degraded (Kauffman and Krueger 1984; Chaney et al. 1990; Williamson et al. 1992; Trimble and Mendel 1995; Fitch and Adams 1998; Clary 1999; Scarsbrook and Halliday 1999; Strand and Merritt 1999; Soto-Grajales 2002; Parkyn et al. 2003). Numerous studies have found that livestock access creates a combination of reduced channel boundary resistance and increased stream power such that bank erosion and subsequent mass failure occur (Chaney et al. 1990; Platts 1991; Marston 1994; USBLM 1994). The reduction of riparian vegetation may also result in increased water temperatures and fine bed sediment; hence, aquatic invertebrate density may be reduced (Rabeni and Minshall 1977; Minshall 1984; Chaney et al. 1990; Wohl and Carline 1995; Braccia and Voshell 2006). A review by Belsky et al. (1999) indicated that approximately 85% of riparian livestock studies concluded that livestock access negatively impacts stream morphology and aquatic habitat.

The USDA Natural Resources Conservation Service's (NRCS) Conserva-tion Reserve Enhancement Program (CREP) is the most funded conservation program in Virginia, with $91 million in federal and state funding allocated for the program yearly (VDCR 2006). The goal of CREP is to reduce sediment and nutrients runoff from agricultural lands into streams through livestock exclusion and the establishment of pollution-filtering vegetation (Blann et al. 2002; USDA NRCS 2005; VDCR 2006). Unfortunately, since the CREP program is voluntary, implementation of livestock exclusion practices tends to happen piecemeal, resulting in the protection of short stretches of stream, while the remaining stream lengths continue to be impacted by livestock access.

Few best management practices (BMPs), including livestock exclusion practices, are monitored to evaluate their effectiveness following implementation (Kondolf 1995; Kondolf and Micheli 1995; Bash and Ryan 2002; Blann et al. 2002; Roni et al. 2002; Palmer et al. 2005). The goal of this research was to determine the success of livestock exclusion practices in improving channel morphology, riparian vegetation, and benthic macroinvertebrate assemblages over time. To accomplish this, we focused on two main objectives: (1) assess the effectiveness of existing livestock exclusion projects in southwestern Virginia and (2) evaluate the time to achieve improved channel morphology and benthic macroinvertebrate assemblages once exclusion projects have been implemented.

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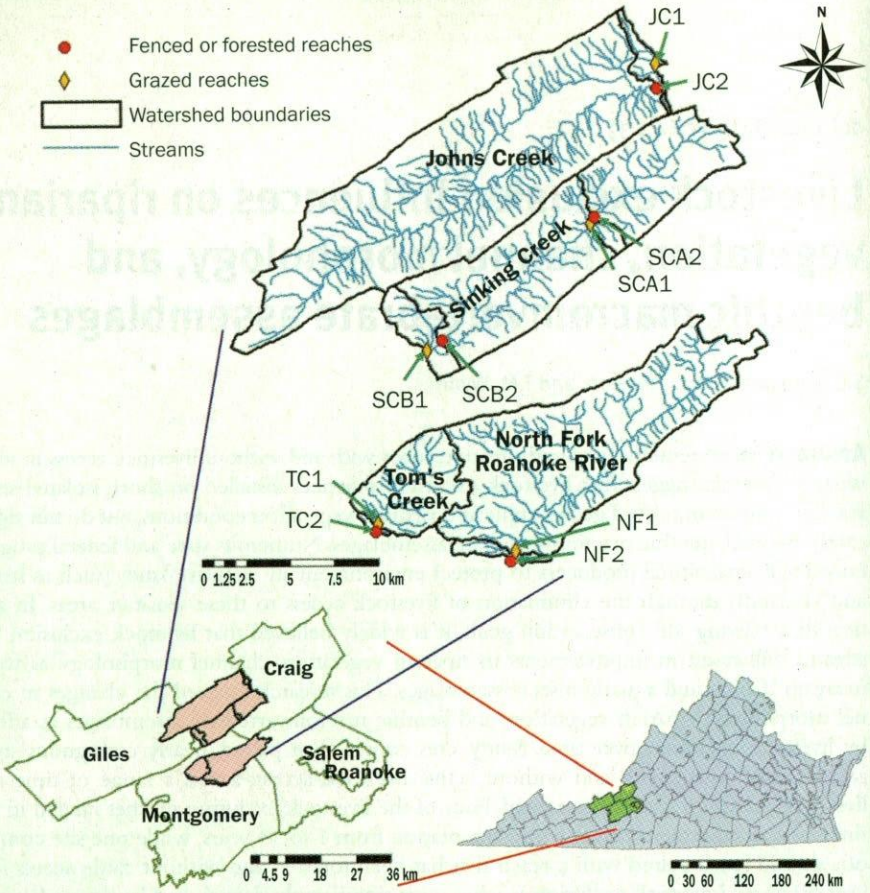
Materials and Methods

Study Location and Watershed Characteristics. Five pairs of contiguous stream reaches with and without livestock access were studied during 2006. The paired reaches are located in agricultural watersheds in southwestern Virginia on the North Fork of the Roanoke River, Tom's Creek, Johns Creek, and Sinking Creek (figure 1). The reaches with livestock access to the stream were used by heifer cattle as water and shade sources; between 15 and 60 head of cattle grazed the banks and accessed the streams daily (table 1). Since the paired reaches essentially have the same contributing watershed, any differences found were assumed to be caused by local conditions (e.g., soils, topography, riparian condition, and livestock or no livestock). The grazed reaches had unrestricted livestock access. Four of the livestock exclusion reaches ranged in time since BMP implementation from one to 14 years, while one site consisted of a grazed reach paired with an ungrazed reach that has been forested for at least 50 years. The upstream and downstream extents of each reach were located with a global positioning system (GPS) with differential correction. Watershed boundaries were delineated for each study reach using the National Watershed Boundary Dataset for Virginia (VDCR 2007) as a base map; the watersheds boundaries were then refined to match the reach outlets using heads-up digitizing in ArcGIS 9.0 (ESRI, Redlands, California) (figure 1; table 2). The watershed-level land use characteristics for each reach were then quantified using the watershed boundaries intersected with digital land use spatial data layers from 2000 (RESAC 2003) (table 1).

Figure 1
Location of study sites for livestock exclusion study in Virginia.



Notes: TC1 = grazed Tom's Creek reach. TC2 = livestock exclusion Tom's Creek reach. SCA1 = grazed Sinking Creek A reach. SCA2 = livestock exclusion Sinking Creek A reach. SCB1 = grazed Sinking Creek reach. SCB2 = livestock exclusion Sinking Creek B reach. NF1 = grazed North Fork of the Roanoke River reach. NF2 = livestock exclusion North Fork of the Roanoke River reach. JC1 = grazed Johns Creek reach. JC2 = livestock exclusion Johns Creek reach.

Stream Morphology. To quantify the physical condition of each reach, surveying and standard stream morphology assessment methods were used (Harrelson et al. 1994). Study reaches were surveyed for a minimum length of 20 times the bankfull width using a Leica TC 307 total station (Leica Geosystems AG, St. Gallen, Switzerland). Longitudinal profiles were surveyed to determine stream gradient, water surface slope, and the location of bed features, such as riffles and pools. Channel cross-sectional profiles were surveyed for two riffles and two pools along each reach and used to quantify channel dimensions and floodplain features. The cross-sectional data were used to determine bankfull width, average bankfull depth, width to depth ratio, and cross-sectional area. Average, or hydraulic, depth in each cross section was determined by dividing the cross-sectional area by the width at bankfull stage (Mecklenburg 2004). The width to depth ratio was calculated in each cross section as the bankfull top width divided by the average bankfull depth. The means of the bankfull hydraulic depth and width to depth ratio were then calculated over the four surveyed cross sections in each reach.

Reach-averaged grain-size distributions were determined in each bedform type (pools and riffles) using a modification of the Wolman (1954) pebble count (Riley et al. 2003). Within each reach, 100 pebbles were measured in two pools and two riffles for a total of 400 pebbles using a US Forest Service gravelometer. Median particle sizes (d_{50}) were computed for the entire reach, as well as for the riffles separately; the percent fines in each reach were determined by calculating the percent of bed material less than 2 mm (0.08 in) in diameter. Embeddedness was estimated within a single riffle in each study reach using methods described in Barbour et al. (1999). The number of large woody debris (LWD) pieces within the bankfull channel greater than 0.10 m (0.33 ft) diameter and 1.0 m (3.3 ft) length were counted (Montgomery et al. 1995).

The Virginia Department of Environmental Quality (VDEQ) Reach Condition Index (RCI) was used to evaluate stream geomorphic condition, adjustment processes, and reach sensitivity (USEPA and VDEQ 2006). The RCI was determined based on a field evaluation of channel condition, instream habitat, and riparian land use and land cover.

Table 1
Paired reach and watershed characteristics for livestock exclusion study conducted in southwestern Virginia.

Paired site	Reach	Livestock number or exclusion practice	Grazing density (AU ha^{-1})	Forest	Urban/ residential	Natural grass	Pasture	Croplands	Other
Toms Creek	TC_{access}	30 cattle	27.6	43.1%	36.8%	1.9%	6.4%	10.2%	1.5%
	$TC_{exclude}$	Fenced 2 years	5.0	43.8%	36.2%	2.1%	6.3%	10.1%	1.5%
Sinking Creek-A	SCA_{access}	20 cattle	18.4	56.2%	6.6%	0.6%	9.4%	26.9%	0.4%
	$SCA_{exclude}$	Fenced 2 years	3.7	56.7%	6.6%	0.6%	9.0%	26.7%	0.4%
Sinking Creek-B	SCB_{access}	15 cattle	13.8	58.3%	9.3%	1.6%	8.6%	21.8%	0.3%
	$SCB_{exclude}$	Fenced 4 years	34.2	57.2%	9.2%	1.7%	8.7%	22.8%	0.3%
North Fork Roanoke River	NF_{access}	60 cattle	55.2	60.9%	11.2%	1.6%	7.9%	18.0%	0.3%
	$NF_{exclude}$	Fenced 14 years	32.0	60.5%	11.7%	1.6%	7.9%	18.0%	0.3%
Johns Creek	JC_{access}	40 cattle	36.8	78.0%	7.2%	11.1%	0.0%	0.0%	3.6%
	$JC_{exclude}$	Forested	0.0	78.0%	7.5%	10.9%	0.0%	0.0%	3.7%

Note: AU ha^{-1} = animal units per hectare of grazed pasture. Values for AU from National Range and Pasture Handbook (USDA NRCS 2003).

Streambank Soils and Riparian Vegetation. Soil bulk densities were measured in the streambanks of each reach by taking an undisturbed soil core at each depositional layer using a 5 cm by 5 cm (2 in by 2 in) aluminum cylinder with a slide hammer (Wynn and Mostaghimi 2006). Since the soil samples were taken from alluvial streambanks, the soil layers that were present were linked more to depositional events and did not exhibit a typical upland soil profile. Additionally, the reaches with livestock access had highly disturbed banks with little distinct layering in areas of intense trampling. Soil cores were taken at two random locations on the side of each streambank for a total of four locations per soil layer. Because the streambank soil stratigraphy varied between sites, the samples were not taken the same distance down the bank face, but were instead taken in each depositional layer. The soil samples were weighed and dried at 105°C (221°F) within eight hours of sampling (USDA NRCS 2004). Livestock grazing intensity varied along the study reaches; therefore, the median bulk density was determined to capture the reach-wide impacts of livestock access. All groundcover below 1 m (3.3 ft) height was cut to ground level in 1 m^2 (3.3 ft^2) areas; groundcover greater than 1 m (3.3 ft) height within the 1 m^2 (3.3 ft^2) area was left uncut (Bonham 1989). These vegetation samples were dried in an oven at 60°C (140°F) and then weighed to determine dry biomass at each site (kg ha^{-1} [lb ac^{-1}]).

Instream Habitat and Water Chemistry. The Rapid Habitat Assessment (RHA) was used to evaluate the habitat quality of each reach (Barbour et al. 1999). The RHA assigns a score ranging from 0 (poor habitat condition) to 200 (optimal habitat condition) to a stream reach based on streambed characteristics, channel morphology, bank structure, and riparian zone.

To quickly evaluate gross stream-water chemistry, a grab-sample was taken at each paired reach and a laboratory analysis was conducted for nitrate and orthophosphate concentrations (USEPA 1983; Clesceri et al. 1998). These grab samples were taken the same day benthic macroinvertebrates were collected and were primarily taken to ensure that there were no major differences in water

Table 2
Drainage area, stream order, distance between reaches, and soil texture in livestock exclusion study conducted in southwestern Virginia.

Reach	Drainage area (km^2)	Stream order*	Reach position in pair	Distance between reaches† (m)	Reach length (m)	Bank soil texture
TC_{access}	25.7	3	Upstream	216.8	237.0	Sandy clay loam
$TC_{exclude}$	26.4	3	Downstream	–	159.8	Sandy loam
SCA_{access}	40.5	3	Downstream	612.4	201.3	Sandy clay loam
$SCA_{exclude}$	38.2	3	Upstream	–	117.0	Sandy clay loam
SCB_{access}	107.2	4	Downstream	1145.2	142.9	Sandy loam
$SCB_{exclude}$	97.4	4	Upstream	–	198.7	Sandy loam
NF_{access}	105.8	4	Upstream	656.4	174.2	Sandy clay loam
$NF_{exclude}$	109.3	4	Downstream	–	267.2	Sandy clay loam
JC_{access}	171.0	5	Downstream	1237.4	421.0	Sandy loam
$JC_{exclude}$	166.5	5	Upstream	–	184.3	Sandy loam

Notes: TC = Tom's Creek. SCA = Sinking Creek A. SCB = Sinking Creek B. NF = North Fork of the Roanoke River. JC = Johns Creek.

* USGS (1:24,000) quad sheets were used to determine stream order. Blue line streams were considered 1st order.

† The distance from the outlet of the upstream reach to the inlet of the downstream reach.

chemistry within paired sites and across pairs. The margin of error for the laboratory analysis of the nitrate and orthophosphate concentrations was 0.02 and 0.01 mg L^{-1}, respectively.

Benthic Macroinvertebrate Assemblages. Benthic macroinvertebrate samples were taken between the middle of June and the end of August 2006 with a D-frame dip net (standard 500-μm [0.02-in] mesh); the paired reaches were sampled within a day of each other to eliminate any temporal variation in sampling between the paired reaches. Samples were taken at the three riffles within the middle of each study reach at the left and right side of each riffle, for a total of six sampling areas. The substrate was disturbed in an area approximately 0.9 m by 0.3 m (3 ft by 1 ft) immediately upstream of the net by rubbing the surface of the large rocks and kicking vigorously for 30 to 60 s. All benthic macroinvertebrates for each site were combined and stored in 95% ethanol. In the lab, the samples were soaked with water and then sieved through a 500-μm (0.02-in) mesh. The pooled samples were then subsampled using the methods described in Caton (1991) to produce 200 ± 10% or 20% of the organisms for each reach. The samples for each study reach were identified to the family level following Voshell (2002) and Merritt and Cummins (1996).

The Virginia Stream Condition Index (SCI) was calculated to evaluate the benthic macroinvertebrate assemblages at each reach (USEPA and VDEQ 2003). The SCI is composed of eight metrics, including (1) taxa richness; (2) ephemeroptera, plecoptera, and trichoptera (EPT) index; (3) percent ephemeroptera; (4) percent plecoptera and trichoptera minus hydropsychidae; (5) percent scrapers; (6) percent chironomidae; (7) percent dominant taxon; and (8) Modified Family Biotic Index (MFBI). The SCI results in a score ranging from 1 (severe stress) to 100 (excellent condition) for each reach based on the benthic macroinvertebrate assemblages identified. The scores determined for each reach were categorized based on Aquatic Life Use (ALU) tiers, which were developed based on data collected from 350 streams in Virginia and ranged from severe stress (<42) to excellent (>73) (VDEQ 2006).

Statistical Analysis. Percent differences were computed for geomorphic characteristics, substrate size, vegetation and soil parameters, water chemistry, benthic macroinvertebrates metrics, and rapid geomorphic and habitat assessment results from the paired data set as follows:

$$X_{pd} = \frac{X_{exclude} - X_{access}}{X_{access}} \times 100, \qquad (1)$$

where X_{pd} is the percent difference computed for a given variable (%), $X_{exclude}$ is the value of the variable in the livestock exclusion reach, and X_{access} is the value of the variable in the paired reach with livestock access. The Shapiro-Wilk test for normality was performed on each variable. Most of the variables indicated that the null hypothesis of normality should be rejected ($p < 0.05$); therefore, we chose to perform our statistics using nonparametric tests, which require less restrictive assumptions about the data. A one-sample Wilcoxon Signed Rank test was run in SAS-JMP to determine if the percent differences between paired reaches differed significantly from zero (SAS-JMP, SAS Institute Inc., Cary, North Carolina). Differences between reaches and treatments were tested using a nonparametric version of a two-way ANOVA. The Friedman test was conducted in Minitab using the sites as blocks and the livestock access or exclusion condition as the treatment (Minitab 1998). The physical data were normalized to remove the influence of watershed size by dividing each parameter by either watershed area or the square root of watershed area (e.g., cross-sectional area was divided by watershed area). A statistical significance level of 0.05 was assumed.

Results and Discussion

Stream Morphology. In general, livestock exclusion increased stream depth and parameters dependent on depth. The hydraulic depth was significantly deeper in the livestock exclusion reaches, and the ratio of the bankfull width to the hydraulic depth was smaller in the livestock exclusion reaches ($p = 0.031$; $p = 0.31$; table 3). Results of the Friedman test also indicated the hydraulic radius was larger in the livestock exclusion reaches ($p = 0.025$), while the maximum depth was greater in the reaches with livestock access ($p = 0.025$; table 4). The bankfull widths showed no significant response to livestock exclusion ($p = 0.22$; table 3). Additionally, there were no significant differences in the sinuosity or overall water surface slope between the paired reaches. The RCI, a qualitative measure of geomorphic condition, ranged from 1.3 and 5.8; the livestock exclusion reaches had a significantly higher score than the grazed reaches ($p = 0.031$) (tables 3 and 4).

Similar mixed results were reported in previous studies of livestock impacts on streams. Parkyn et al. (2003) and Wohl and Carline (1996) determined that stream width did not change with increased livestock access, while Wohl and Carline (1996) concluded that stream depth was not affected by increased livestock access. In contrast, Clary (1999) and Scarsbrook and Halliday (1999) determined that wider reaches resulted from increased livestock access. Numerous studies conducted on the geomorphic response to livestock exclusion have determined that the bankfull width to hydraulic depth ratio decreases following livestock exclusion (McDowell and Magilligan 1997; Clary 1999; Nagle and Clifton 2003).

There were no significant differences in the amount of LWD between grazed and livestock exclusion reaches (table 3). Wohl and Carline (1996) and Harding et al. (2006) also found no significant differences in LWD between forested and agricultural reaches. Wohl and Carline (1996) attributed the lack of LWD in the grazed reaches to the young age of trees in the riparian zone. Also, Harding et al. (2006) hypothesized that storm events had moved LWD from the forested reach downstream to the agricultural reaches. The age of trees in most of our study riparian zones was less than 14 years, which most likely contributed to our finding that the amount of LWD was not significantly greater in the livestock exclusion reaches. Since all of our reaches have upstream segments with a wide range of land uses, storm events could have moved LWD downstream, resulting in the variability in the amount of LWD between study reaches.

There were no significant differences in the percent fines, embeddedness, or d_{50} between grazed and livestock exclusion reaches; however, the riffle d_{50} substrate size was usually larger in the livestock exclusion reaches ($p = 0.063$) (table 3). Similarly, Clary (1999) found no significant differences in percent fines or embeddedness between grazed and ungrazed reaches. In contrast, many studies have found that the substrate percent fines and the degree of embeddedness increase with more frequent livestock access to the stream (Wohl and Carline 1996; Nerbonne and Vondracek 2001; Braccia and Voshell 2006). The lack of difference in d50, percent

Table 3

Cross-sectional dimensions, large woody debris count, Reach Condition Index, and substrate characteristics, including d_{50} (median bed substrate particle size) and riffle d_{50} (median riffle bed substrate particle size), for livestock exclusion study conducted in southwestern Virginia.

Reach	Bankfull width (m)	Bankfull hydraulic depth (m)*	Bankfull width to depth ratio	LWD	RCI	RHA	d_{50} (mm)	Riffle d_{50} (mm)
TC_{access}	9.0	0.7	13.1	11	2.1	74	7	11
$TC_{exclude}$	5.4	0.8	7.0	8	3.4	103	18	37
% diff	-40	13	-46	-27	62	39	147	236
SCA_{access}	9.1	0.4	21.8	5	2.9	87	42	38
$SCA_{exclude}$	5.6	0.5	12.2	7	4.2	129	17	24
% diff	-38	6	-44	40	45	48	-60	-37
SCB_{access}	15.2	0.6	25.0	7	2.9	118	19	17
$SCB_{exclude}$	13.6	0.6	23.5	0	4.2	141	49	49
% diff	-11	2	-6	-100	45	20	158	188
NF_{access}	12.2	0.7	19.7	12	1.3	95	26	27
$NF_{exclude}$	13.4	0.8	19.4	4	4.2	131	41	39
% diff	10	15	-1	-67	223	38	58	44
JC_{access}	12.5	0.9	16.9	26	2.1	98	45	36
$JC_{exclude}$	17.1	1.1	16.5	8	5.8	175	40	53
% diff	37	17	-2	-69	176	79	-11	47
p-value†	0.22	0.031	0.031	0.094	0.031	0.031	0.22	0.053

Notes: LWD = the number of large woody debris in each reach greater than 0.10 m diameter and 1.0 m length. RCI = Reach Condition Index; scores range from 0 (poor) to 7 (excellent) and indicate geomorphic reach condition. RHA = Rapid Habitat Assessment; scores range from 0 (poor) to 200 (excellent) and indicate reach-scale habitat quality. d_{50} = the median substrate size of four hundred pebbles in two riffles and two pools. Riffle d_{50} = the median substrate size of the two hundred pebbles counted in two riffles. TC = Tom's Creek; SCA = Sinking Creek A; SCB = Sinking Creek B; NF = North Fork of the Roanoke River; JC = Johns Creek.

* Hydraulic depth over four cross sections was calculated by dividing the cross-sectional area by the top width at bankfull stage.

† Probability that the percent difference between paired reaches differ significantly from zero (Wilcoxon Signed Rank test); values less than 0.05 were considered significant.

fines, and embeddedness in this study likely resulted from upstream sediment sources, which could have overshadowed the impacts of local livestock management differences.

Streambank Soils and Riparian Vegetation. Many studies have found that soil bulk density, a measure of soil compaction, increases with grazing intensity (Alderfer and Robinson 1949; Orr 1960; Rauzi and Hanson 1966; Bryant et al. 1972; Wood and Blackburn 1984); however, there were no significant differences in bulk density between the paired reaches in this study (figure 2). The lack of significant differences in soil bulk density might be due to the low grazing intensities in this study reaches (table 1) or rapid recovery in soil bulk density with freezing and thawing (Wheeler et al. 2003).

The median amount of groundcover vegetation was two times greater in the livestock exclusion reaches than the grazed reaches ($p = 0.031$; figure 2; table 4). Schulz and Leininger (1990), Williamson et al. (1992), and Flenniken et al. (2001) found similar responses of groundcover vegetation to livestock removal. In fact, Schulz and Leininger (1990) found the grazed riparian areas had approximately five times more bare ground than areas that had livestock exclusion for 29 years.

Instream Habitat and Water Chemistry. There was a significant difference in the RHA scores between the grazed and livestock exclusion reaches ($p = 0.031$) (table 3). Similar results were found for the RHA ($p = 0.025$) using the nonparametric Friedman test, which had median values of 131 and 95 for the reaches with and

Table 4

Evaluation of significant differences between reaches with and without livestock access using the nonparametric Friedman test; data are blocked by sites and treatments are livestock with access to or excluded from the stream reach. Data that are dependent of watershed size were normalized by dividing by watershed area or the square root of watershed area.

Treatment	Median hydraulic depth ($m\ ha^{-0.5}$)	Median maximum depth ($m\ ha^{-0.5}$)	Median hydraulic radius ($m\ ha^{-0.5}$)	Median bankfull width to hydraulic depth ratio	Median average bed slope of riffles	Median RCI score	Median groundcover biomass ($kg\ ha^{-1}$)	Median RHA score	Median average length of riffles ($m\ ha^{-0.5}$)
Excluded	0.077	1.082	0.204	16.2	0.535	4.2	2359	131	3.270
Access	0.068	1.186	0.179	17.8	1.325	2.9	1076	95	1.919
p-value	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025

without livestock exclusion, respectively (table 4). Therefore, both statistical techniques provided similar results, providing additional confidence in their validity.

The VDEQ screened several sets of Virginia habitat quality data to determine that the Ridge and Valley Ecoregion usually has a range of RHA scores between 120 and 140. A habitat score below 120 indicates the reach has poor habitat condition, while a score above 140 indicates the reach has good habitat conditions (VDEQ 2006). The RHA scores from this study were generally on the lower end of the VDEQ Ridge and Valley Ecoregion scores in the grazed reaches (74 to 118) and on the higher end in the livestock exclusion reaches (103 to 175). Stone et al. (2005) and Braccia and Voshell (2006) used the RHA to distinguish habitat conditions between study reaches in Virginia with varying degrees of cattle density. Braccia and Voshell (2006) assigned an RHA score of 156 to their reference reach in southwestern Virginia, which is lower than the score for the forested reach in this study (175).

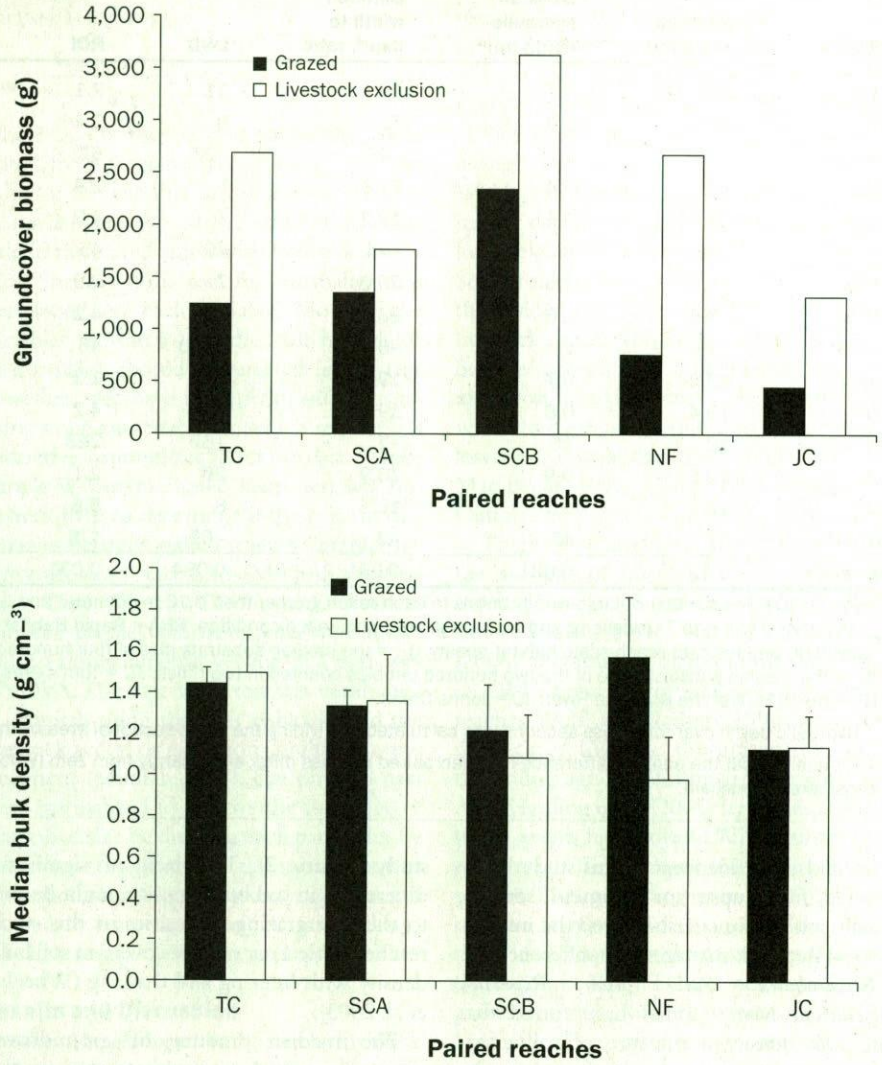
There were no significant differences in the nitrate and orthophosphate concentrations between the grazed and livestock exclusion reaches. In contrast, Galeone et al. (2006) determined that nitrate and phosphorus concentrations increase with increased agricultural land use. The overall summer orthophosphate concentrations range from 0.00050 to 0.12 mg L^{-1} for streams in the Ridge and Valley Ecoregion (USEPA 2000). The orthophosphate concentrations for this study reaches (0.017 to 0.12 mg L^{-1}) were within this range and were higher than the mean concentration (0.016 mg L^{-1}) for streams in the Ridge and Valley Ecoregion (USEPA 2000). The nitrate concentrations for this study reaches (0.040 to 0.081 mg L^{-1}) fell in the lower range of values typical of nitrite/nitrate concentrations in Ridge and Valley Ecoregion streams (0.003 to 8.950 mg L^{-1}; USEPA 2000).

Benthic Macroinvertebrates. We tested for differences in the EPT index, the SCI, as well as the eight components used in the SCI. There were no significant differences in any of the benthic macroinvertebrate metrics. In the interest of space, we only report Taxa Richness, EPT index, and SCI (table 5). Nerbonne and Vondracek (2001), Wohl and Carline (1995), and Parkyn et al. (2003) similarly found no significant differences in the benthic macroinvertebrate metrics between grazed and livestock exclusion reaches. Stone et al. (2005) found no significant differences in the EPT scores between reaches with a range of agricultural land use; however, Scarsbrook and Halliday (1999) and Galeone et al. (2006) found higher EPT scores with decreased livestock access to the stream. In addition, Galeone et al. (2006) found that taxa richness increased with increased agricultural land use. Carline and Walsh (2007) found that macroinvertebrate diversity indices did not change after fencing, but density did increase. However, our sampling methods were not designed to measure density.

Nerbonne and Vondracek (2001) attributed the lack of benthic macroinvertebrate response in their study in southeastern Minnesota to the influence of watershed characteristics rather than localized livestock grazing influences. Watershed topography and land use dictate the conditions to which benthic macroinvertebrates respond, including temperature, discharge, flood frequency and magnitude, and delivery of sediment and nutrients (Troelstrup and Perry 1989;

Figure 2

Groundcover vegetation biomass and median bulk density for each paired reach in livestock exclusion study conducted in southwestern Virginia.



Notes: TC = Tom's Creek. SCA = Sinking Creek A. SCB = Sinking Creek B. NF = North Fork of the Roanoke River. JC = Johns Creek. Bulk density error bars indicate +1 standard deviation with $n \geq 4$. The median bulk density value was determined considering all the bulk densities taken at each soil horizon in each study reach.

Table 5
Taxa richness, Ephemeroptera, Plecoptera, Trichoptera index, and Stream Condition Index for livestock exclusion study conducted in southwestern Virginia.

Reach	Taxa richness	EPT index	Stream Condition Index
TC_{access}	14	7	60.6
$TC_{exclude}$	17	7	60.1
% diff	21	0	-1
SCA_{access}	20	11	73.2
$SCA_{exclude}$	23	13	69.5
% diff	15	18	-5
SCB_{access}	21	11	74.5
$SCB_{exclude}$	17	9	72.8
% diff	-19	-18	-2
NF_{access}	14	7	60.0
$NF_{exclude}$	17	7	59.3
% diff	21	0	-1
JC_{access}	18	9	70.5
$JC_{exclude}$	18	8	73.7
% diff	0	-11	5
p-value*	0.19	0.70	0.86

Notes: EPT = Ephemeroptera, Plecoptera, Trichoptera. TC = Tom's Creek. SCA = Sinking Creek A. SCB = Sinking Creek B. NF = North Fork of the Roanoke River. JC = Johns Creek.

* Probability that the percent differences between paired reaches differ significantly from zero (Wilcoxon Signed Rank test); values less than 0.05 were considered significant.

Nerbonne and Vondracek 2001). Parkyn et al. (2003) attributed the lack of benthic macroinvertebrate response to livestock exclusion to variations in shading between reaches. The age, length, and vegetation type in buffers affect the amount of shading available to the stream reach and may alter the stream temperature to which certain benthic macroinvertebrate assemblages are sensitive (Quinn et al. 1992; Rutherford et al. 1999; Parkyn et al. 2003). In our study reaches, four of the livestock exclusion reaches were most likely not mature enough (2 to 14 years) to significantly increase shading and therefore influence stream temperature.

Time to Recovery. To evaluate the time required for recovery in channel morphology once exclusion projects are implemented, several parameters were plotted on 1:1 scatter plots (figure 3). Only the RCI plot displayed a relationship to time (figure 3); however, the RCI is a qualitative measure estimated using visual observation. Therefore, one might expect RCI to have the most rapid response to livestock exclusion practices. Similar qualitative geomorphic assessments were conducted by Parkyn et al. (2003), Scrimgeour and Kendall (2003), and Harding et al. (2006), and they all found improvements in bank stability indices following livestock exclusion. Galeone et al. (2006) also conducted qualitative visual geomorphic assessments and determined that the available substrate cover, pool to riffle ratio, and bank stability showed improvements within four years following streambank fencing for livestock exclusion.

Closer inspection of the bankfull widths (figure 3) highlights the complexity involved in evaluating changes over time since exclusion. Numerous studies have reported that livestock access results in wider stream channels (Trimble and Mendel 1995; Clary 1999; Scarsbrook and Halliday 1999). Trimble and Mendel (1995) presented a schematic representing the recovery of a stream channel after livestock exclusion that suggested that, once the cattle were removed, the grasses along the streambank would be allowed to grow, resulting in increased sediment trapping and channel narrowing. Additionally, there are numerous studies that suggest that small streams with riparian forests are wider than those with non-forested, or grassy, vegetation (Davies-Colley 1997; Trimble 1997; Hession et al. 2003). While the data set in this study is small (n = 5), the sites where cattle were recently excluded (2, 2.5, and 4 years) fall below the 1:1 line in figure 3 (livestock exclusion narrower than grazed), and the sites with older exclusion (14 and >50 years) plot above the line. In addition, the oldest site plots the farthest above the 1:1 line, suggesting it has widened the most. Such a progression from a narrow, grassy channel to a wider, forested channel has been predicted by several authors (Davies-Colley 1997; Trimble 2004). The complex interactions between cattle impacts and the influence of riparian vegetation on channel width highlight the need for more research to better understand the processes and timing of channel recovery and change after livestock exclusion.

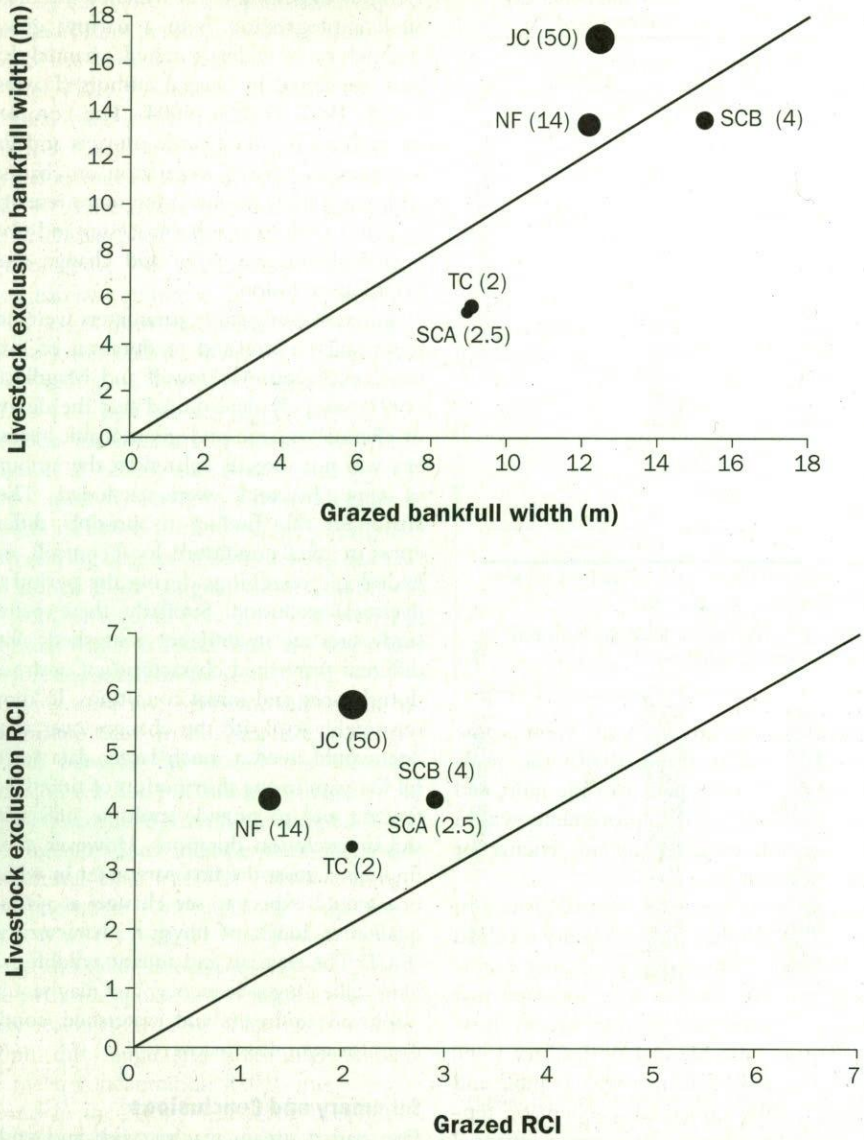
The remaining study parameters were not significantly correlated to duration of livestock exclusion. McDowell and Magilligan (1997) similarly determined that the degree of channel aquatic and geomorphic recovery was not directly related to the amount of time livestock were excluded. They attributed this finding to possible differences in initial conditions, local controls, and hydrologic conditions during the period of livestock exclusion. Similarly, these paired study sites are in different watersheds with different watershed characteristics, upstream disturbances, and initial conditions. To more thoroughly evaluate the changes over time, one would need a much larger data set to fill the gaps in the distribution of time since fencing and to provide multiple sites with similar exclusion durations. However, these findings suggest the first parameter in which one would expect to see changes is a visual qualitative index of physical characteristics (RCI). The riparian and aquatic wildlife will likely take longer to recover and may require improved upstream and watershed conditions for complete recovery.

Summary and Conclusions

Five paired stream reaches with and without cattle access in southwestern Virginia were studied to (1) assess the effectiveness of existing livestock exclusion projects in improving stream morphology, streambank and riparian characteristics, and benthic macroinvertebrate assemblages and (2) determine the range of improvement expected over time since livestock exclusion implementation. There were significant differences in stream morphology and riparian vegetation between paired grazed and livestock exclusion reaches; however, the benthic macroinvertebrate assemblages were not significantly different. The RCI, a qualitative geomorphic assessment methodology, increased with time since livestock exclu-

Figure 3

Bankfull width in two riffle and two pool cross sections and Reach Condition Index (RCI) for the paired reaches in the livestock exclusion study conducted in southwestern Virginia.



Notes: TC = Tom's Creek. SCA = Sinking Creek A. SCB = Sinking Creek B. NF = North Fork of the Roanoke River. JC = Johns Creek. The number in the parenthesis indicates the duration of time that livestock exclusion practices have been in place on the livestock exclusion reaches. Points above the 1:1 line indicate that the parameter is larger in the livestock exclusion reaches, and points below the 1:1 line indicate that the parameter is larger in the grazed reaches. To observe a time distribution for improved geomorphic condition, the data points would follow a trend with two years as being the closest to the 1:1 line and 50 years as the furthest away.

sion. All other parameters showed no clear temporal response.

The lack of benthic macroinvertebrate assemblage response likely resulted from the overall land use, soils, and geologic features of the watersheds rather than the localized impacts of livestock access to the stream reach. These results suggest that short sections of livestock exclusion may not result in improved biological integrity. Rather, a watershed-wide initiative to reduce negative impacts (including livestock access) to streams must be taken to meet the goals of the US Clean Water Act. Roughly $91 million is budgeted annually for the CREP program to fence livestock out of streams; however, the fencing and buffering of small isolated stream reaches without addressing additional stressors at the watershed-scale may not be the best restoration strategy. We suggest a more targeted approach to implementing BMPs, such as livestock exclusion that focuses on long stretches of streams and/or entire watersheds.

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