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Streambank Erosion Associated with Grazing Practices in Central Kentucky

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Abstract. *Research into the effects of cattle grazing on stream health has been well documented in the western portion of the United States, but is lacking in the east. Western researchers have estimated that 80% of the damage incurred by stream and riparian systems in these arid environments was from grazing livestock. Stream and riparian damage resulting from grazing includes alterations in watershed hydrology, changes to stream morphology, soil compaction and erosion, destruction of vegetation, and water quality impairments. The objective of this project was to provide the agricultural community with a better understanding of the impacts of cattle grazing on stream bank erosion so as to enhance current cattle production methods on farms in the humid region of the U.S. The project site, located on the University of Kentucky's Animal Research Center, consisted of two replications of three treatments: control, selected BMPs with free access to the stream, and selected BMPs with limited access to the stream. Fifty permanent cross sections were established throughout the project site. Over a two year period, 18 surveys were conducted using conventional surveying techniques. Changes in stream cross sectional area were used to quantify soil loss or gain associated with the different treatment levels Results from this project indicated that streambank erosion can be minimized though the incorporation on a BMP system (with or without a fenced riparian area). In the absence of a protected riparian zone, grazing managers should modify their practices to minimize cattle activity (i.e. flash grazing, no grazing), and associated erosion along streambanks, during periods characterized by higher flows and/or hot humid conditions.*

Keywords. BMP, management, soil loss, riparian.

Introduction

Over a quarter of the land area within the United States is used for grazing activities supporting nearly 100 million cattle and calves (USDA, 1997; Vesterby and Krupa, 1997). While these cattle are a major component of the U.S. agricultural trade, improperly managed grazing cattle can contribute significant pollutant loads to the nation's waterways. The U.S. Environmental Protection Agency (EPA) (2000) identified agriculture as the predominant source of nonpoint source pollution (NPS), impairing 48% of the assessed river and stream miles. The two leading pollutants for rivers and streams were pathogens and sediment, constituents linked to cattle production (CAST, 2002; EPA, 2000; Belsky et al., 1999; Clark 1998; Nader et al., 1998; Kauffman and Krueger, 1984). Cattle producers often use rivers and streams as the primary water source for their grazing livestock, resulting in increased activity along the water's edge. Streambank erosion occurs when livestock hooves trample banks and excessive grazing reduces riparian vegetation (Belsky et al., 1999).

Compounding the issue of streambank erosion is the role of stream sedimentation in fecal bacteria survival rates. Research indicates that bottom sediments serve as reservoirs for fecal bacteria. Stephenson and Rychert (1982) noted greater concentrations of *E.coli* in bottom sediments as compared to overlying waters. Van Donsel and Gelreich (1971) detected similar results with concentrations of sediment fecal coliforms 100 to 1,000 times greater than concentrations for overlying waters. However, fecal coliforms do not remain trapped in bottom sediments. Disturbance of the bottom sediments (i.e. storm events or cattle activity) often results in higher *E coli* concentrations in the overlying waters from the process of resuspension (Stephenson and Rychert, 1982). Furthermore, streambank erosion rates may be a more serious problem for alluvial channels whose banks are comprised of fine particles. Howell et al. (1996) discovered that the mortality rates of fecal coliforms were much lower in sediments with a high percentage of clay particles with similar trends noted for fecal streptococci. Burton et al. (1986) observed that *E.coli* survived longer in sediments containing at least 25% clay. The importance of particle size to fecal coliform survival rates indicates that erosion reduction along streams dominated by silt/clay materials is critical for reducing fecal contamination.

Controlling or reducing agricultural NPS is an important step towards improving the quality of our nation's streams. A system of best management practices (BMPs) is the most likely means of achieving this goal in an effective and cost-efficient manner. However, developing a successful NPS pollution control program targeting grazing practices can be difficult, especially in the humid region of the United States. The majority of research on the impacts of cattle grazing and the subsequent effect of BMPs to reduce these impacts has occurred in the western portion of the U.S. (McInnis and McIver, 2001; Belsky et al., 1999; Clark., 1998; Magilligan and McDowell, 1997; Godwin and Miner, 1996; Platts and Nelson, 1985; Kauffman et al., 1983; Miner et al., 1982). These studies often examined a single BMP rather than a system of BMPs. While it is important to examine the individual effects of BMPs for reducing NPS associated with grazing activities, an understanding of the water quality benefits derived from a system of BMPs may provide insights that allow for more informed managerial decisions. Effectively minimizing the impacts of grazing on stream health will likely necessitate the incorporation of both structural (i.e. riparian buffers) and cultural (i.e. managed grazing) BMPs (Logan, 1990).

Few studies in the humid region of the United States have examined the impacts of grazing BMPs on water quality (Line et al., 2000; Sheffield et al., 1997; Owens et al., 1989). Only isolated studies examined streambank erosion associated with the use of a grazing BMP, though they yielded promising results. Sheffield et al. (1997) noted a 77% reduction in streambank erosion along a southwest Virginia stream following implementation of an off-stream water source. At a Tennessee stream, Trimble (1994) measured a six-fold increase in gross bank erosion along uncontrolled grazing sites as compared to reaches with exclusion fencing. While these studies provided useful information, they could not fill all the gaps in knowledge. Notably, these studies examined the effectiveness of a single BMP versus the system of controls more commonly implemented on farms, the erosive forces of cattle grazing and stream flow were not separated, and comparisons were not made between fenced and non-fenced treatments. As evident by these gaps in information, a need exists for obtaining additional information with regard to grazing BMPs, especially BMP systems, and their effectiveness at reducing streambank erosion. To fill the void, this project sought to determine the ability of two BMP systems consisting of an alternate water source, alternate shade sources, and pasture improvements (one system also had a 9.1 m wide riparian zone equipped with a 3.7 m wide stream crossing) to reduce streambank erosion along two central Kentucky streams. Results from this project will provide stakeholders with necessary information regarding the effectiveness of these BMP systems for reducing streambank erosion in central Kentucky and possibly within the humid region of the United States.

Methods

Study Area

The study area is located on the University of Kentucky's Animal Research Center (ARC) in Woodford County, Kentucky. The climate is humid and temperate with a mean monthly rainfall ranging from 66 mm in October to 118 mm in July with a mean annual rainfall of 1150 mm (University of Kentucky Agricultural Weather Center, 2004). The ARC is characterized by gently rolling hills with elevations ranging from approximately 240 to 260 meters above mean sea level. One stream drains much of the ARC through two bedrock bottom second-order tributaries, Camden Creek and Pin Oak, whose confluence is near the property boundary of the ARC. Camden Creek flows in a southwesterly direction, and Pin Oak flows in a northwesterly direction (fig. 1). The ARC is located in a significant karst area with approximately 30% of the farm draining to sinks (Fogle, 1998). Soils at the study site are derived from limestone and consist of the Hagerstown (fine, mixed, mesic Typic Hapludalfs) and McAfee (fine, mixed, mesic Mollic Hapludalfs) soil series along Pin Oak and the Hagerstown and Woolper (fine, mixed, mesic Typic Argiudolls) soils series along Camden Creek (Jacobs et al., 1994). The land use along the lowermost reaches of these tributaries is pasture. The pastures at the ARC are dominated by endophyte (*Neotyphodium coenophialum*) infected tall fescue (*Festuca arundinacea*).

Treatments

Data collection involved two replications (one replicate was located on Camden Creek and the other on Pin Oak) of three treatments (i.e. pasture plots), listed in downstream order as 1) BMPs and a fenced 9.1 m wide riparian area to exclude cattle from the stream equipped with a 3.7 m wide stream crossing (Riparian), 2) BMPs with free stream access (BMP), and 3) free access with limited BMPs (Control) (fig 1). The limited BMPs included in the control treatment predominately consisted of natural shade, since the decision was made not to remove any old growth trees from the site for the purpose of this study. Treatments were ordered such that the anticipated severity of the treatment increased in the downstream direction. The implemented BMPs included an alternate water source, alternate shade (started in July 2003), and pasture improvements consisting of fertilizer plots and herbicide plots, each 30.5 m × 30.5 m. Fertilizer (ammonia-nitrate) was applied annually to all pasture plots at a rate of 45 kg/ha prior to the start of the grazing season. The fertilizer plots received an additional 11 kg/ha of fertilizer and the herbicide Select(R)® from Valent Chemical was applied, at a rate recommended for growth regulation of *F. arundinacea*, to the herbicide plots (150 mL/ha with 300 mL/ha surfactant) in April 2003. The pasture plots used for each treatment within a replication spanned the stream with approximately equal stream frontage within each replicate. The replication, along Camden Creek, contained pasture plots with an area of approximately 2 ha while the other pasture plots, located along Pin Oak, were nearly 3 ha. The difference in plot size for the replications resulted from the amount of land available for the study. Every attempt was made to ensure that plot characteristics such as topographical features, soil, existing shade, riparian characteristics (if applicable), and linear feet of stream frontage was as consistent as possible among the treatments. High tensile electrical fence was used to separate the pasture plots and to exclude cattle from the riparian areas. Cattle stocking densities were varied throughout the grazing seasons based on the amount of available forage (Table 1). However, the maximum practical rate was used with stocking rates remaining the same for all treatments within a replication. Initial stocking rates were set at 1,300 kg/ha. Cattle were weighed on a monthly basis during the grazing season (typically mid-April until late October). During 2002, the stocking density was maintained by feeding hay when forage supply became limited due to drought conditions.

Cross Sectional Areas

Using guidelines set forth by Harrelson et al. (1994), fifty permanent cross sections (23 along Camden Creek and 27 along Pin Oak) were established for surveying erosion levels. Cross sections were erected at both random locations and near areas anticipated as frequent travel paths for cattle. Each cross section was established perpendicular to stream flow. Cross-sectional surveys were conducted monthly from April 2002 through October 2003 resulting in a total of 18 surveys of each section. Data from all of the cross-sectional surveys were used in the analysis except for those collected during January 2003 (when the soil was frozen).

Computation of cross-sectional area changes were performed for all 50 cross sections and for all 17 periods. The cross sectional areas ($A_{T,j,k}$) for each cross section and for each sample period were computed using

$$A_{T,j,k} = \Sigma A_i = \left(x_i - x_{i-1}\right)\left(\frac{y_i + y_{i-1}}{2}\right) \qquad \text{(eqn. 1)}$$

where x is the lateral station along the cross section and y is the elevation at the corresponding lateral station. Lateral station is represented by the subscript i, sample period is represented by the subscript j, and cross section location is represented by the subscript k. At each individual cross section, increased values of $A_{T,j,k}$ from one cross-sectional survey period to the next indicate soil loss or erosion while decreased values of $A_{T,j,k}$ from one cross-sectional survey period to the next indicate soil gain or aggradation.

Cross-sectional areas computed for each individual cross section at each sampling period were then normalized using eqn. 2. All of the cross-sectional areas for each individual cross section and each period were normalized in relation to the original, respective cross-sectional surveys as indicated in eqn. 2, where $A_{norm,j,k}$ is the normalized cross sectional area for each cross section at each sampling period and the subscript o represents the original cross sectional area (i.e. April 2002).

$$A_{norm,j,k} = \frac{A_{T,j,k}}{A_{T,o,k}} \qquad \text{(eqn. 2)}$$

Values of $A_{norm,j,k}$ greater than one indicate that the normalized area for a cross-sectional survey increased in relation to the original cross-sectional survey (i.e. erosion). Similarly, aggradation was seen when values of $A_{norm,j,k}$ were less than the original cross-sectional survey.

Finally, the fraction of change ($F_{j,k}$) between cross-sectional areas as compared to the original cross sectional survey was determined for each cross section and each period by eqn. 3.

$$F_{j,k} = \frac{A_{norm,j,k}}{A_{norm,j-1,k}} = \frac{A_{T,j,k}}{A_{T,j-1,k}} \qquad \text{(eqn. 3)}$$

As with eqn. 2, values of $F_{j,k}$ greater than one indicate erosion, less than one indicate aggradation, and values equal to one indicate no change.

Cattle Positions

Global positioning system (GPS) collars, GPS_2200 Small Animal GPS Location Systems (Lotek Engineering, Inc., Newmarket, ON)*, were used to collect position information on a sample of cattle from each pasture plot. Detailed descriptions of the GPS collars were presented in Turner et al. (2000) and Agouridis et al. (2004). Position information was collected over seven, 18-day periods during May, August, and November 2002 as well as April, June, July and October 2003. A five-minute sample interval, the smallest permitted with the GPS collars, was selected. Data from the GPS collars were filtered and differentially corrected allowing use of only the highest quality position points in the analysis (Agouridis et al., 2004).

Prior to the start of the project, a base map identifying key pasture features was created using a Real Time Kinematic Global Positioning System (RTK-GPS) with a published horizontal accuracy of 20 mm. Key pasture features included the streambanks of Camden Creek and Pin Oak, fences, trees, and all BMPs (i.e. alternate water sources, alternate shade sources and pasture improvements). The base map was used in conjunction with data collected from the GPS collars during the seven cattle-monitoring periods to characterize cattle activity along the streambanks. A 5 m buffer from the edge of the streambanks was created in ArcView® for each pasture plot. The five-meter buffer was selected because it represents the maximum horizontal error associated with the GPS collars in an open field environment (Agouridis et al., 2004). For each GPS collar-monitoring period, all GPS collar data points that fell within this buffer were totaled ($GPS_{s,p,j}$). A five-meter buffer around each cross section was overlain on the five-meter stream buffer, and the all of the GPS collar data points that fell within this overlay were totaled ($GPS_{ov,p,j}$). Finally, the percentage of cattle activity within five meters of the stream that was associated with each cross section and each GPS monitoring period was computed using

$$GPS_{j,k} = \frac{GPS_{ov,p,j}}{GPS_{s,p,j}} \qquad \text{(eqn. 4)}$$

where the subscript s denotes the five-meter stream buffer around the stream; the subscript ov denotes the overlay of the five-meter stream buffer around the stream and five-meter cross section buffer around the cross section; and the subscript p denotes pasture plot that contained the cross section.

Stocking Densities

All cattle on each of the pasture plots were weighed at 28-day intervals during the grazing season for both years of the project. The final weights and cattle numbers for each pasture plot and for each period were used to compute stocking densities (Table 1). Every attempt was made to maintain equivalent stocking densities across the pasture plots within a replicate for a given period. Stocking densities varied with available forage, ranging from 1670 kg/ha at the early stages of the grazing seasons to 720 kg/ha during the latter part of the grazing seasons.

Stream Discharges

Stream discharge data were collected at the most downstream edge of each replication (i.e. Camden Creek and Pin Oak) using compound 90° V-notch weirs and ISCO 4220 flow meters (pressure transducers) (fig. 1). Discharge data were collected at 10-minute intervals at the two weirs for the duration of the study. Each weir was located approximately 5 m downstream from the respective most downstream treatments. Average discharges were computed from flow values collected during the period prior to each cross-sectional survey. For example, if a cross-sectional survey was performed on September 3, 2002 and the subsequent survey was conducted on October 2, 2002, then the average discharge for the period was assigned to the October survey. Since flow data were not available at each cross section, ArcView® was used to approximate the outlet flow contributions to each cross section based on the cross section's watershed area (eqn. 5).

$$Q_{j,k} = \left(\frac{Q_{w,j}}{WS_w} \right) WS_k \qquad \text{(eqn. 5)}$$

Q represents discharge (m^3/s), WS represents watershed area, and the subscript w represents the weir.

Time

The parameter time was defined as the time lapse or interval from the start of cross-sectional data collection (i.e. shortly prior to cattle introduction in April 2002) until the end of the project (i.e. immediately following cattle removal in November 2003). A time value in relation to the original cross-sectional survey was computed for each subsequent cross-sectional survey, and ranged from 59 days in June 2002 to 571 days in November 2003.

Statistical Analysis

To develop a predictive streambank erosion model, backward stepwise linear regression and multiple linear regression analyses were performed using SigmaStat® (SPSS, 1997). Because several independent variables were identified as potentially significant, a backward stepwise regression was performed to eliminate nonsignificant independent variables from the model. Johnson (1998) recommended using a backward elimination process when the number of prospective independent variables is less than 15 and a stepwise comparison for greater than 15 independent variables. SigmaStat® incorporates both the backward and stepwise procedures into one statistical test, allowing for the initial incorporation of all potential independent variables with subsequent checks on the significance of the remaining independent variables each time one variable is eliminated (SPSS, 1997). The fraction of change between cross-sectional areas ($F_{j,k}$) served as the dependent variable while the independent variables consisted of time, treatment, stocking density, cross section associated cattle activity ($GPS_{j,k}$), and cross-sectional flow ($Q_{j,k}$). Both methods of normalizing the cross-sectional areas (i.e. in relation to the original survey and in relation to the previous survey) were examined. Checks were performed for normality, constant variance, power, multicollinearity, and outliers.

Results and Discussion

Backward Stepwise Linear Regression

Only the cross-sectional areas normalized with respect to the original cross-sectional survey (i.e. eqn. 2) demonstrated a significant relationship with any of the examined independent variables. After including treatment, time, cross-sectional cattle activity, stocking density, and cross-sectional flow as independent variables, all but two variables were eliminated (Table 2). The variables treatment ($P<0.001$) and cross-sectional cattle activity ($P=0.021$) were identified as significant predictors of the fraction of change between cross-sectional areas ($F_{j,k}$). The independent variables were eliminated in the order of time ($P=0.875$), stocking density ($P=0.478$), and cross-sectional flow ($P=0.076$).

Multiple Linear Regression

Following the identification of the significant independent variables that best predicted the change in cross-sectional area for each cross section and for each period ($F_{j,k}$), a multiple linear regression analysis was conducted. Both treatment and cross-sectional cattle activity were used as the dependent variables. The analysis generated the following model

$$F_{j,k} = 0.978 + 0.011 * T + 0.0231 * GPS_{j,k} \qquad \text{(eqn. 6)}$$

where the variable T represents treatments (BMP system and riparian zone = 1; BMP system only = 2; free access/control = 3). The model was able to explain 40% of the change in cross-sectional areas through the independent variables treatment ($P<0.001$) and cross-sectional cattle activity ($P=0.041$). The assumptions of normality and constant variance were valid, no outliers were identified, no issues with multicollinearity were identified, and power was 100%.

Standard errors for the coefficients were 0.0033 for the constant, 0.0014 for T and 0.0113 for $GPS_{j,k}$.

In addition to the multiple linear regression analysis, a correlation matrix was constructed to determine the strength of the relationships between the variables in the model (Table 3). As seen in eqn. 6, both treatment and cross-sectional cattle activity were positively correlated to change in cross-sectional area. Treatment had a stronger positive correlation ($P<0.001$) than cross-sectional cattle activity ($P=0.015$) with change in cross-sectional area, $F_{j,k}$. Treatment and cross-sectional cattle activity were not significantly correlated ($P=0.122$), which was somewhat surprising in light of the significance of these two variables in the model. Since the correlation matrix examined linear correlations, lack of correlation between treatment and cross-sectional cattle activity may be attributable to a slightly nonlinear relationship. For instance, both the BMPs with free stream access treatment and the free stream access without the BMPs (control) treatment had greater instances of cattle activity than the BMPs with a fenced riparian area treatment. The difference between the two treatments that allowed cattle free access to the stream was of a small magnitude. However, the magnitude of the difference was much greater between the treatments that allowed free stream access and the treatment consisting of the BMPs with a fenced riparian area where access to the stream was extremely limited.

Significant Variables

Based on the model presented in eqn. 6, increased treatment ranking and cross-sectional cattle activity produced increases in soil loss at the cross section ($R^2=0.40$). A treatment ranking of one, indicative of the BMP system and riparian zone combination, resulted in less soil loss than either the BMP system (ranking of two) or the free access/control treatment (ranking of three). Likewise, as the percentages of time the cattle spent within a cross-sectional area along the stream increased, the greater the rates of soil loss.

The significance of treatment, as defined in this analysis, with respect to cross sectional area is a relatively new result for two important reasons. First, this study was holistic in design, examining a management system rather than individual components of a management system such as alternate water source (Sheffield et al. 1997), exclusion fencing (Trimble, 1994; Kauffman et al., 1983), or grazing intensity (George et al., 2002; Marlow et al., 1987) on streambank erosion. Logan (1990) points to the need of multiple types of BMPs (i.e. structural and cultural) for reducing NPS, indicating the importance of a holistic approach. Secondly, the project results indicate that additional streambank erosion benefits are attainable by incorporating a fenced riparian zone into a grazing BMP system. Both Camden Creek and Pin

Oak have bedrock lined channel beds throughout the study area as well as the entire upstream reaches. Therefore, sediment supply to the stream is limited to streambanks and contributions from runoff. Previous geological research at the ARC revealed the importance of groundwater as Gremos (1994) discovered nearly 80 sinkholes and sinks (rounded depressions) on the ARC. Fogle (1998) reported that nearly 30% of the ARC drains to sinks. Maury and McAfee, the dominant soil series at the ARC, are in the hydrologic soil group B, which are characterized by moderate infiltration rates (Haan et al., 1994; Jacobs et al., 1994). With limited amounts of runoff contributing to the flow in Camden and Pin Oak, erosion in these channels most likely occurred along the banks.

As for the independent variable cross-sectional cattle activity, its inclusion in the model was an expected result as previous research into the impacts of cattle grazing on streambanks highlighted the damaging effects of hooves (Belsky et al., 1999; Sheffield et al., 1997; Trimble, 1994; Kauffman et al., 1983). Unlike previous studies, this project was able to relate changes in cross-sectional area to cattle presence through the incorporation of GPS collars. Additionally, information regarding the amount of time cattle spent within a specific cross sectional area during a lengthy monitoring period (up to 18 days) was easily obtained. By using GPS technology, a more accurate and extensive cattle activity data set was collected, as compared to previous research efforts, allowing for a better understanding of the relationship between cattle activity and streambank erosion.

One inconsistency with the model is its prediction of soil loss or gain, depending on the treatment, when cattle activity is zero. Assuming no cattle activity, the model predicted that treatment one, the BMP system with a fenced riparian zone, would result in soil gain (F_j=0.989). For treatment two, the BMP system, the model predicted no change (F_j=1). The third treatment, free access/control, was predicted to result in soil loss (F_j=1.011). With the absence of cattle activity, streambank erosion rates within all three treatments should be the same unless another unrecognized variable(s) is significant. Results from the backward stepwise linear regression analysis indicated that the independent variable cross-sectional flow was significant at the 10% level (P=0.076). Cross-sectional flow is a variable that will always be present at the study site, since both Camden Creek and Pin Oak are perennial streams. Furthermore, cross-sectional flow is greater in the downstream direction, which corresponds to the treatment order (i.e. treatment rank 3 is in the most downstream direction while treatment rank 1 is in the most upstream direction). As indicated by Lane (1955), increases in flow produce increases in sediment, assuming median particle size and slope remain constant. Inclusion of cross-sectional flow in the multiple linear regression analysis provided greater substance to the model (eqn. 7).

$$F_{j,k} = 0.976 + 0.0100 * T + 0.0259 * GPS_{j,k} + 0.0324 * Q_{j,k} \quad \text{(eqn. 7)}$$

Nearly 41% of the change in cross-sectional area was explained by the three variables treatment ($P<0.001$), cross-sectional cattle activity ($P=0.021$) and cross-sectional flow ($P=0.020$). The model, as presented in eqn. 7, was better equipped to handle instances of no cattle activity with the addition of the independent variable cross-sectional flow.

Eliminated Variables

The independent variables eliminated from the model (i.e. time and stocking density) were as interesting as the significant independent variables included in the model. Basic assumptions made with regards to streambank erosion, over the course of the study, at Camden Creek and Pin Oak helped explain the nonsignificance of independent variable time. These assumptions were that following the introduction of cattle, erosion would occur steadily over time until the cattle were removed, and little recovery would take place after their removal during the off grazing season. Following cattle removal, erosion rates would decrease and possibly plateau, then again increase following the re-introduction of the cattle. The basic flaws with this assumption were that 1) cattle activity within a cross section would be constant throughout the time the animals were in the pasture, 2) the amount of time required for measurable erosion to occur was at least a month (i.e. the selected sample interval), and 3) the recovery phase would take much longer than the few months of the off grazing season (i.e. late December 2002 through April 2003). Plots of GPS collar data revealed that while cattle favored certain sections of the stream, the rates with which they frequented these sections varied considerably throughout the study (fig. 2). This indicates that while cattle activity was strongly related to erosion, a time period of recovery or a plateau existed for the majority of the cross sections surveyed during the grazing season, leading to the conclusion that erosive events happened rather rapidly.

The second misconception was that the period of time needed for the occurrence of measurable erosion was likely much shorter than the sampling interval. Equation 7 points out the importance of treatment in reducing the amount of time the cattle spent along the streamside, and subsequently near the cross sections, impacting the process of erosion. As reported by Belsky et al. (1999), cattle damage streambanks by reducing streambank stability (i.e. shear force from hooves), making the banks more susceptible to the erosive forces of high flows. However, these negative impacts could have occurred on the order of a few days rather than one or more months indicating that streambank erosion can occur quickly with increased grazing activity and flow in the cross section. Hence, several cycles of erosion could have occurred within one particular sampling period while a second sampling period could have contained one or even none.

The third misconception was that the recovery phase would more closely resemble the broken leg model proposed by Sarr (2002). With the broken leg model, recovery occurs at a slow rate following the removal of grazing pressures, as it takes a much longer time for the stream to reach a state of equilibrium. In actuality, Camden Creek and Pin Oak more resembled the rubber-band model characterized by quick recovery periods following the removal of grazing pressures (Sarr, 2002). Under the rubber band model, time would have continued to increase over the course of the study, but erosion would not have occurred as a result of cattle grazing (i.e. treatment or activity) during the off-season. While time was a linearly increasing variable, change in cross-sectional area (i.e. erosion) was not.

In addition to time, stocking density was a nonsignificant variable in the model. Stocking density was greatest during the early cooler months of the grazing season when forage was plentiful. As the grazing season continued, stocking densities in the pasture plots decreased as forage availability decreased. Furthermore, temperature and humidity increased throughout the grazing season, until the latter part of September, October and November of each year. Cattle sought relief from the increased temperature and humidity levels by wading in the stream (fig 4). Compounding the issue was the presence of endophyte-infected fescue, which causes increases in the body temperature of cattle as a result of decreased peripheral circulation (Al-Haidary et al., 2001). The period of greatest heat stress during 2002 coincided largely with the lowest stocking density, thereby decreasing the amount of cattle activity that could occur within the cross sections. If stocking densities had remained constant throughout the 2002 grazing season, the level of erosion would have likely been greater during this hotter, more humid period, possibly making stocking density a significant variable. For the 2003 grazing season, average temperatures during the hotter months of June through September were approximately 4.5ºC degrees cooler on average, creating less of a need for the cattle to cool themselves in the stream.

Conclusions

Streambank erosion along two bedrock bottom second-order perennial streams was positively correlated with treatment type (i.e. BMP system and riparian zone =1, BMP system only = 2, and free access/control = 3), cattle activity within the cross section, and cross sectional flow. As expected, erosion levels within a cross section increased as these three independent variables increased. Elimination of the independent variable time from the model pointed to the rapid rate at which erosive forces and recovery occurred, likely on the order of hours to a few days rather than at monthly intervals as captured by our sampling schedule. This observation was supported by the elimination of stocking density from the model. Our moderate stocking densities, which were based on the amount of available forage, were not necessarily good predictors of cattle activity along the stream reaches. During the cooler, less humid periods characteristic of the early grazing seasons, cattle activity along the stream reaches was lower than during the hotter, more humid months typical of the mid to latter parts of the grazing seasons. The positive correlation of cattle activity within the cross sections to change in cross-sectional areas indicates that if stocking density had remained constant throughout the study rather than fluctuating with the amount of available forage, the rate of erosion during the hotter, more humid months would be greater. Future work should seek to quantify the effects of constant stocking rates on streambank erosion, as fluctuating stocking densities based on biomass production was a type of cultural BMP employed in this project. Many farmers within the humid region will maintain stocking densities by providing supplemental feed during periods of low biomass production.

Results from this study highlight the importance of viewing grazing management from a holistic viewpoint rather than from a component oriented format. Each of the independent variables examined for inclusion in the model pointed to important managerial strategies, even if two of these independent variables were excluded. Provision of BMP systems, both with and without the excluded riparian zone, reduced erosion levels over the grazing system with no BMPs. The addition of the variable cross-sectional cattle activity highlighted the importance of including a riparian zone protected by exclusion fencing to the BMP system, for no cattle activity will occur in this protected area. Enhancing the managerial perspective is the importance of cross-sectional flow, time and stocking density. By realizing that the livestock damage to streambanks is more prevalent under wetter conditions and that this damage can occur within a few hours to a few days, managers can better tailor their operations to reduce streamside grazing during these sensitive times. Finally, livestock managers need to understand the attractiveness of the cool waters of a stream to cattle grazing on endophyte infected fescue during the hot, humid months of the grazing season. While it is important to graze cattle in accordance with the amount of forage available in a pasture (i.e. appropriate stocking density), the amount of cattle activity along streambanks poses greater erosive threat. In conclusion, results from this project suggest that streambank erosion can be minimized by using a BMP system with further reductions attainable by incorporating a riparian zone protected by fencing. Without the addition of a protected riparian zone, grazing managers must readily adapt to changes in stream flow as well as temperature and humidity by reducing cattle access to streamside areas when these parameters increase.

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Table 1. Stocking Densities (kg/ha) for Each Pasture Plot and Each Period.

Period	Camden Creek			Pin Oak		
	1§	2	3	1	2	3
June 2002	1429.7*	1428.2	1430.6	1394.5	1420.9	1431.3
July 2002	1521.1	1613.8	1554.0	1543.8	1551.3	1519.7
August 2002	829.4	846.0	777.1	802.5	833.3	814.9
September 2002	829.0	825.9	783.9	808.1	846.2	834.8
October 2002	820.6	824.5	776.0	806.3	826.4	722.4
November 2002	--*	--	--	--	--	--
December 2002	1040.5	1005.0	972.8	790.7	949.7	885.5
January 2003	0.0**	0.0	0.0	0.0	0.0	0.0
February 2003	0.0	0.0	0.0	0.0	0.0	0.0
March 2003	0.0	0.0	0.0	0.0	0.0	0.0
April 2003	0.0	0.0	0.0	0.0	0.0	0.0
May 2003	1338.2	1332.6	1304.6	1277.5	1263.3	1263.4
June 2003	1462.7	1443.8	1410.2	1361.9	1358.8	1340.1
July 2003	1482.1	1465.8	1427.9	1342.3	1350.6	1326.6
August 2003	1508.4	1502.5	1451.8	1298.1	1377.5	1364.4
September 2003	1546.7	1574.7	1497.0	1443.3	1470.6	1435.2
October 2003	769.9	782.7	782.3	737.2	764.7	738.9

§Treatments are as follows: BMPs and fence riparian zone = 1, BMPs with free stream access = 2, and no BMPs with free stream access (control) = 3.

*No data available because scale malfunctioned.

**No cattle were present on the pasture plots.

Table 2. Average and Standard Deviation Values for the Independent and Dependent Variables Examined in the Multiple Linear Regression Model.

Cross Section*	Treatment**	$F_{j,k}$ ***	$GPS_{j,k}$***	$Q_{j,k}$ (cms)	Stocking Density (kg/ha)
C1	1	1.03 ± 0.02	0.00 ± 0.00	0.09 ± 0.08	971.89 ± 579.88
C2	1	1.01 ± 0.01	0.02 ± 0.02	0.09 ± 0.08	971.89 ± 579.88
C3	1	0.97 ± 0.01	0.03 ± 0.02	0.09 ± 0.08	971.89 ± 579.88
C4	1	0.98 ± 0.01	0.01 ± 0.03	0.09 ± 0.08	971.89 ± 579.88
C5	1	0.98 ± 0.00	0.18 ± 0.10	0.09 ± 0.08	971.89 ± 579.88
C6	2	1.02 ± 0.01	0.18 ± 0.04	0.09 ± 0.08	976.36 ± 584.99
C7	2	1.03 ± 0.01	0.05 ± 0.01	0.09 ± 0.08	976.36 ± 584.99
C8	2	1.00 ± 0.01	0.07 ± 0.03	0.09 ± 0.08	976.36 ± 584.99
C9	2	1.00 ± 0.01	0.07 ± 0.02	0.09 ± 0.08	976.36 ± 584.99
C10	2	1.00 ± 0.00	0.10 ± 0.04	0.09 ± 0.08	976.36 ± 584.99
C11	2	1.01 ± 0.01	0.14 ± 0.05	0.09 ± 0.09	976.36 ± 584.99
C12	3	1.00 ± 0.01	0.08 ± 0.07	0.09 ± 0.09	944.54 ± 569.21
C13	3	1.04 ± 0.03	0.10 ± 0.03	0.09 ± 0.09	944.54 ± 569.21
C14	3	1.03 ± 0.01	0.06 ± 0.03	0.09 ± 0.09	944.54 ± 569.21
C15	3	1.03 ± 0.01	0.09 ± 0.05	0.09 ± 0.09	944.54 ± 569.21
C16	3	1.01 ± 0.01	0.09 ± 0.02	0.09 ± 0.09	944.54 ± 569.21
C17	3	1.02 ± 0.01	0.15 ± 0.09	0.09 ± 0.09	944.54 ± 569.21
C18	3	0.99 ± 0.02	0.05 ± 0.02	0.09 ± 0.09	944.54 ± 569.21
C19	3	0.99 ± 0.03	0.05 ± 0.04	0.09 ± 0.09	944.54 ± 569.21

Table 2 (continued).

Cross Section*	Treatment**	$F_{j,k}$ ***	$GPS_{j,k}$***	$Q_{j,k}$ (cms)	Stocking Density (kg/ha)
C20	2	1.01 ± 0.01	0.08 ± 0.06	0.09 ± 0.09	976.36 ± 584.99
C21	2	1.03 ± 0.01	0.06 ± 0.03	0.09 ± 0.09	976.36 ± 584.99
C22	3	1.01 ± 0.01	0.14 ± 0.07	0.09 ± 0.09	944.54 ± 569.21
C23	2	1.02 ± 0.01	0.10 ± 0.03	0.09 ± 0.09	976.36 ± 584.99
P1	1	0.99 ± 0.01	0.00 ± 0.01	0.06 ± 0.06	907.08 ± 545.01
P2	1	0.97 ± 0.01	0.00 ± 0.00	0.06 ± 0.06	907.08 ± 545.01
P3	1	0.99 ± 0.01	0.00 ± 0.00	0.06 ± 0.06	907.08 ± 545.01
P4	1	0.99 ± 0.01	0.01 ± 0.01	0.06 ± 0.06	907.08 ± 545.01
P5	1	0.97 ± 0.01	0.00 ± 0.00	0.06 ± 0.06	907.08 ± 545.01
P6	1	0.99 ± 0.02	0.27 ± 0.08	0.06 ± 0.06	907.08 ± 545.01
P7	2	0.99 ± 0.01	0.02 ± 0.01	0.07 ± 0.06	934.21 ± 550.36
P8	2	1.00 ± 0.01	0.42 ± 0.11	0.07 ± 0.06	934.21 ± 550.36
P9	2	1.01 ± 0.00	0.30 ± 0.11	0.07 ± 0.06	934.21 ± 550.36
P10	2	1.00 ± 0.01	0.03 ± 0.02	0.07 ± 0.06	934.21 ± 550.36
P11	2	1.00 ± 0.00	0.02 ± 0.02	0.07 ± 0.06	934.21 ± 550.36
P12	2	1.01 ± 0.00	0.05 ± 0.05	0.07 ± 0.06	934.21 ± 550.36
P13	2	1.00 ± 0.00	0.02 ± 0.02	0.07 ± 0.06	934.21 ± 550.36
P14	3	1.03 ± 0.02	0.02 ± 0.01	--	911.81 ± 545.97
P15	3	1.01 ± 0.01	0.05 ± 0.07	0.07 ± 0.06	911.81 ± 545.97
P16	3	1.01 ± 0.01	0.07 ± 0.06	0.07 ± 0.06	911.81 ± 545.97

Table 2 (continued).

Cross Section*	Treatment**	$F_{j,k}$***	$GPS_{j,k}$***	$Q_{j,k}$ (cms)	Stocking Density (kg/ha)
P17	3	1.00 ± 0.01	0.04 ± 0.02	0.07 ± 0.06	911.81 ± 545.97
P18	3	1.02 ± 0.01	0.21 ± 0.17	0.07 ± 0.06	911.81 ± 545.97
P19	3	0.99 ± 0.01	0.03 ± 0.01	0.07 ± 0.07	911.81 ± 545.97
P20	3	1.00 ± 0.02	0.03 ± 0.04	0.07 ± 0.07	911.81 ± 545.97
P21	2	0.99 ± 0.01	0.10 ± 0.03	0.07 ± 0.06	934.21 ± 550.36
P22	2	1.01 ± 0.01	0.03 ± 0.03	0.07 ± 0.06	934.21 ± 550.36
P23	3	1.02 ± 0.01	0.03 ± 0.02	0.07 ± 0.06	911.81 ± 545.97
P24	2	1.00 ± 0.01	0.02 ± 0.02	0.07 ± 0.06	934.21 ± 550.36
P25	2	0.99 ± 0.01	0.02 ± 0.02	0.07 ± 0.06	934.21 ± 550.36
P26	3	1.00 ± 0.02	0.03 ± 0.03	--	934.21 ± 550.36
P27	2	0.98 ± 0.01	0.09 ± 0.05	0.07 ± 0.07	911.81 ± 545.97

[§]Averaging time since cattle started grazing would have no meaning. The time intervals were 59, 87, 116, 144, 173, 222, 249, 314, 343, 371, 399, 434, 466, 500, 529, and 571 days.

*The letter before the number indicates the stream on which the cross section was located. C denotes Camden Creek and P denotes Pin Oak.

**Treatments are as follows: BMPs and fenced riparian zone = 1, BMPs with free stream access = 2, and no BMPs with free stream access (control) = 3.

***Values are dimensionless.

Table 3. Correlation Matrix for Significant Model Variables.

	Treatment	**$GPS_{j,k}$**	**$Q_{j,k}$§**
$F_{j,k}$	0.382 (P<0.001)*	0.132 (P=0.015)*	0.146 (P<0.001)
Treatment		0.083 (P=0.122)*	0.033 (P=0.358)
$GPS_{j,k}$			0.004 (P=0.941)
$Q_{j,k}$			

§Applicable to eqn. 7.

*Model variables selected by backward stepwise linear regression.

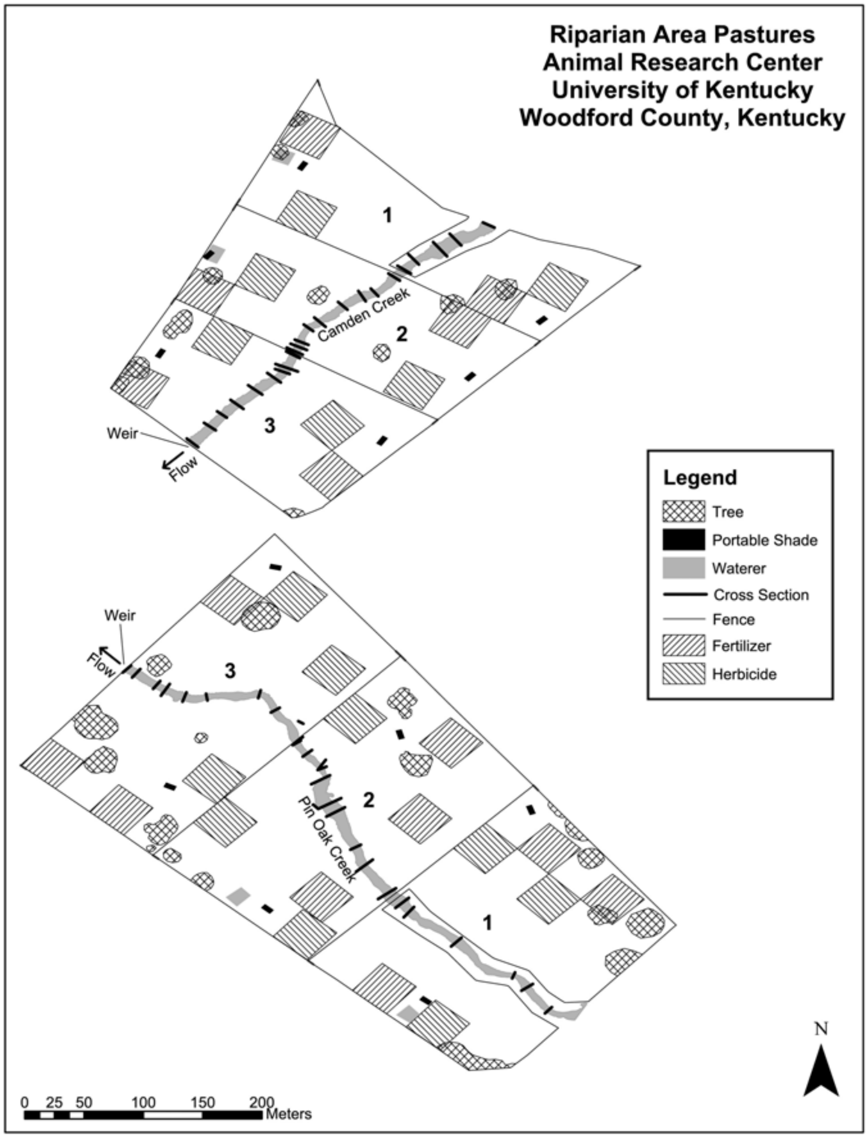

Figure 1. Base Map of Pasture Plots. Plot 1 treatment is the BMPs and a fenced riparian area to exclude cattle from the stream except at a 3.7 m crossing; plot 2 treatment is BMPs with free stream access; and plots 3 are free stream access with no BMPs (control) except for herbicide, fertilizer, and alternate shade that was added in the last few months of the study.

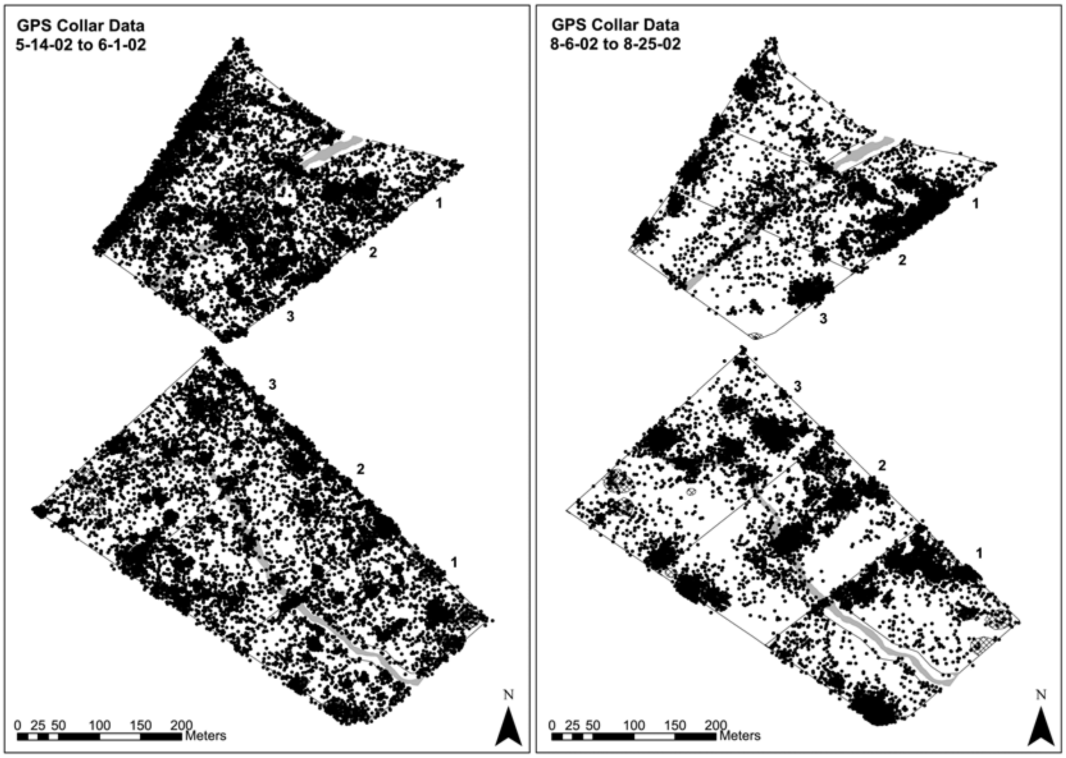

Figure 2. GPS Collar Data. Plot 1 treatment is the BMPs and a fenced riparian area to exclude cattle from the stream except at a 3.7 m crossing; plot 2 treatment is BMPs with free stream access; and plots3 are free stream access with no BMPs (control) except for herbicide, fertilizer, and alternate shade that was added in the last few months of the study.