CATTLE AND WATER QUALITY RESPONSES TO SHADE AND ALTERNATIVE WATER SOURCES IN GRAZED PASTURES IN GEORGIA, USA

by

HARRIS L. BYERS

(Under the Direction of Miguel L. Cabrera)

ABSTRACT

Shade and alternative water sources may affect cattle behavior and stream quality in cattle-grazed pastures. GPS collars were used to monitor cattle behavior in three pastures with unfenced streams as a function of shade and trough availability. Concurrently, water samples were taken during base flow and storm events to monitor changes in stream water quality. Daily time spent by cattle in riparian areas varied between 5% and 10% during warm months and was decreased by the availability of abundant non-riparian shade and water troughs. The stream draining the pasture with the most non-riparian shade had the smallest loads of DRP, TP, TSS, and E. coli. These contaminant loads were decreased when water troughs were available. The results of this study indicate that possible BMPs to reduce contamination from pastures would be to build shade and install a water trough away from the stream.

INDEX WORDS: Cattle behavior, GPS animal tracking, Cattle grazing, Pasture management, Alternative water source, Pasture shade, Stream water quality, Nutrient enrichment, BMP

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Bs.Ed, University of Georgia, 2000

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2004

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August 2004

DEDICATION

When I was in the eighth grade at Lanier Middle School, the guidance counselor, Linda Greenwood, administered an aptitude test to determine what job I might be qualified for. She told me I should be a scientist, to which I stubbornly assured her I would be a farmer; and that was the end of discussion. Not knowing of course several years later, I would be receiving a MS in Agronomy from the University of Georgia, so in hindsight I suspect we were both correct.

However, this achievement would not have been possible without the insight of my eighth grade language arts teacher, Rebecca Clayton. Being raised in a rural agricultural area of Georgia, my oral skills were lazy, sloppy, and often incomprehensible, and I was proud to be a redneck. To this day, I still do not understand her motivation, but Mrs. Clayton was determined not to allow being from a rural area to retard my future. Rather than signing me up for the remedial English track in the ninth grade as many of my friends were destined to follow, she chanced I would be able to rise to the challenge and signed me up for Honors Freshman English. Since then, I have constantly risen above any challenge. I sincerely believe it is because of her decision to challenge me in an advanced academic class that I went on to achieve great things in high school, graduate Magna Cum Laude from UGA, and am now earning an advanced graduate degree from one of the most respected Agronomy Departments in the country. Therefore, this thesis is dedicated to Mrs. Clayton and to all the other teachers who look beyond stereotypical archetypes and see the potential of their students to rise to a challenge and motivate them to achieve great things.

ACKNOWLEDGEMENTS

First, I would like to thank my committee of Drs. Miguel Cabrera, David Radcliffe, and John Andrae for their guidance. I would like to thank the entire staff of the Central Research and Education Center for their help in this study. Specifically, I would like to acknowledge the late Tom Fitzgerald, Chad Westmoreland, Frank Newsome, Gerald Cathey, Timothy Hunnicutt, Johnnie Hash, and Eric Brazil for their assistance in maintaining a healthy grazing system and herd of cattle, for their expertise and assistance in handling and collaring the cows, and for taking water meter readings – you will all be missed. I would like to recognize the valuable contributions of John Rema, Zach Alexander, Jennifer Cummings, and Shelby Finch for their assistance in the field and in filtering, processing, and analyzing the samples. I am grateful to the National Resources Conservation Service for financial support of this project, and to Dr. Glenn Ware for his expertise and assistance in analyzing such an immense amount of data.

I would like to thank my entire family for their prayers and support through graduate school. I would like to especially thank my parents James and Nancy Byers for allowing me to start beekeeping, which gave my mind a much-needed rest, and for gas money to ensure I could always come home. A huge debt of gratitude is due to my father, who for the last two years has been a source of transportation back and forth between home and MARTA, which saved tons of money on parking at the airport. Dr. Rebecca Klaper, my wife is due a great deal of gratitude for her patience in being separated for 2 years.

Finally, I would like to thank the members of Princeton UMC for being a safe harbor during graduate school. Special thanks is due to the pastor, Russell Repetske and his wife for their encouragement, to Larisa Parker for starting a college ministry, and to Bob Allen and his family for welcoming a stranger to their church pew.

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INTRODUCTION

Nonpoint source contamination from agricultural production is a major source of legislation and environmental concern (Morse, 1996). Although point source contamination sites are easy to identify, regulate, and clean up, nonpoint source contamination sites from agriculture are difficult to locate and almost impossible to regulate and control. In the 1998 report to Congress, the USEPA (2000a) estimated that agriculture was responsible for contributing to 59% of the nation's water quality problems in impaired rivers and streams and 31% of the nation's impaired lakes and reservoirs.

Cattle pastures can be major contributors to nonpoint source contamination. Contaminants such as N, P, and bacteria from animal grazing can enter the stream and impose health risks to organisms on a basin-wide scale. Contaminants reach streams either through direct imputs by cattle or through runoff from the pastures. Thus, reducing the amount of time cattle spend in or near streams would be expected to reduce contamination.

Two possible BMPs that may lessen the impact of cattle grazing on water quality are water troughs and shade away from the stream. The first chapter of this thesis discusses the literature as it applies to these two BMPs. The second chapter deals with the effects of water troughs and shade away from the stream on cattle behavior. The third chapter presents the cooresponding changes in water quality to the two tested BMPs.

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CHAPTER 1

LITERATURE REVIEW

Piedmont Soils

Several studies have been published on cattle and water quality in the arid regions of the Western United States where water resources are extremely limited. However, the Piedmont region lacks such studies. In studying riparian areas in the Piedmont, it is important to examine the physical and geomorphology of the soils that surround and create riparian areas, especially the CEC, AEC, infiltration, and surface crusting. These last four properties of Piedmont Ultisols can play significant roles in controlling the amount of contaminated runoff that ultimately reaches the riparian area.

The CEC of Ultisols depends on the amount and type of clay, Fe, Al and Mn oxide contents, organic matter content, soil solution electrolyte concentration, and pH of the horizon (West et al., 1998). The CEC of the soil denotes the ability of the soil to retain cations. The same principle can be applied in riparian filtration. A soil with a high CEC has the ability to retain cation contaminants such as NH_4^+. Since Piedmont soils have a low CEC, their cation contamination retention is low. Cations that are not quickly absorbed by plants may be leached into the groundwater.

A highly weathered soil with a low pH typically has a high AEC. Bellini et al. (1986) showed that the high AEC of Georgian Ultisols required twice as much drainage to leach out monovalent anions. This high AEC means that if an anion enters the soil during a runoff event, the soil could retain the anion and reduce the amount of runoff contamination. The downside to soils with a high AEC is noted during a runoff event. When clay particles with a large amount of anions sorbed to the AEC sites are suspended in runoff, the clays serve as vehicles to spread the anions through the watershed. Anions such as orthophosphate can also be sorbed onto non-exchangeable sites in clays and be transported in eroded sediment. When the sediment settles to the bottom of a lake or enters an anoxic zone, P can be released from the sediment and be made available to aquatic plants, starting the eutrophication process.

For a soil to act as a filter, water infiltration must take place. The most important factor affecting infiltration in Ultisols is surface crust formation. Surface crusting increases runoff and interferes with seedling emergence (West et al. 1998). Miller and Radcliffe (1992) simulated a rainfall of 50 to 90 mm h^{-1} on 25 Ultisols and found that the infiltration rate decreased rapidly during the first 10 to 20 min. At the end of the simulated rainfall, the infiltration rate was <10 mm h^{-1}, suggesting the vast majority of rainfall was leaving the landscape via runoff. Similarly, Chiang et al. (1994) discovered that surface crusting of Georgia soils with a sandy loam textures, low Fe concentration, and high amounts of water-dispersible clay occurred during the first 10 min of rainfall. The surface crusts were 1 to 6 mm thick and had a reduced porosity of 30 to 50%. Early surface crust formation drastically limits the amount of infiltration that can take place and leads to large runoff. It is generally understood that increased granular aggregate structure promotes infiltration. In Piedmont Ultisols with a history of aggressive plowing and mismanagement, the granular structure is degraded and this increases runoff even more. Adding organic matter can offset this effect. Organic matter increases the amount of humus in the A horizon, thus promoting the bonding of clay particles together, thereby increasing the amount of granular structure and increasing the amount of infiltration. Prewetting Ultisols rich in kaolinite, Fe, Al oxyhydroxides, and low in organic C greatly increases the aggregate stability and decreases slaking (Reichert and Norton, 1994).

One final geomorphological characteristic to consider is water movement through saprolite. When contaminated runoff infiltrates the riparian soil and finally passes through the Bt layer in Ultisols, it commonly encounters saprolite. In the Piedmont region, the thickness of underlying saprolite can vary from a few centimeters to several meters (Amoozegar, 1993). Li et al. (1997) demonstrated that soils have the potential for preferential movement of water through macropores rather than through even infiltration through saprolite.

Phosphorus

Over 30 years ago, Ryden et al. (1970) concluded from hydrological studies that P from agricultural and forested watersheds is a primary factor in eutrophication. In pasture grazing, constant livestock manure deposition can lead to increased P in surface runoff. The average total P loading from fresh beef manure is 9.2×10^{-5} kg kg^{-1} live animal mass d^{-1} (ASAE, 1998). Of the total P load, the average orthophosphorus load is 3×10^{-5} kg kg^{-1} live animal mass d^{-1} (ASAE, 1998). Several problems are arising in the realm of nonpoint source P reduction because a balance between economic and environmental benefits have not yet been established. These problems are the greatest in areas where infiltration rates are the lowest and in areas with a large amount of P naturally occurring in the soils (Sims et al., 1998).

Phosphorus exists in organic and inorganic forms. Inorganic P is present in soil in labile, (plant available P) and nonlabile (P that must be released prior to plant uptake) forms. Orthophosphate is the species of labile P found in soil, and exists in two forms HPO_4^{-2} and $H_2PO_4^-$. The species of orthophosphate is determined by the pH of the soil solution whereby at pH 7.2 orthophosphate exists equally in the two forms. The pH of Piedmont soils is below 7.2, so the dominant species of orthophosphate is $H_2PO_4^-$. Sharpley (1995) suggested amorphous HPO_4^{-2} and crystalline P should be considered moderately labile as they have a high dissociation rate. In the same study, Sharpley noted the amount of bioavailable soil P is determined by reactions with organic matter, hydrous oxides, and amorphous and crystalline complexes of Al, Fe, and Ca; whereby the rate and extent limiting factors in these reactions are drainage and landuse. Inorganic nonlabile P exists in crystalline mineral structures such as $FePO_4$ which are slow in becoming labile. Organic P is common in animal manure and must be mineralized by microbes before becoming bioavailable. Reactions catalyzed by phosphatase enzymes can mineralize organic P compounds of inositol phosphates, phospholipids and nucleic acids. Carbon content, soil pH, moisture, and temperature are the major limiting factors in the phosphatase reactions. Inorganic P in the soil solution not taken up by plants can be adsorbed to soil particles, precipitated as secondary minerals, or immobilized by microbes.

Phosphorus delivery to surface waters can occur via surface runoff, leaching, and eroded sediments. Runoff is the main delivery method of bioavailable P to surface waters. Sharpley et al. (1992) suggested that in order to understand environmental responses to agricultural P inputs, the bioavailable P in runoff must be known. A minor secondary route of P transport to surface waters is leaching, though certain landuses can make it a significant method of transport into streams. The potential for P to be leached also depends on the hydrology of the watershed. Soils with a high hydraulic conductivity such as sandy soils, soils high in organic matter, and soils over fertilized with P can lead to P leaching if subsurface runoff occurs (Sims et al., 1998). It has been theorized that historical over fertilization is causing the leaching of P into many agricultural watersheds near large sensitive bodies of water such as Lake Okeechobee and the Everglades in Florida (Daniel et al., 1998). Unlike runoff contamination, leaching is difficult to document and difficult to prevent. Maximizing crop uptake of P and applying only the necessary amount of P a crop can use in one harvest season can reduce leaching (Sims et al., 1998). However, crop removal of P is slow, so other management practices need to be found. Phosphorus adsorbed to sediment can be carried to lakes and reservoirs and deposited as sediment in the benthic zone. Correll (1998) noted that oligotrophic reservoirs remain oxygenated, so most of the P will remain in the sediment. When eutrophic reservoirs become anoxic, adsorbed P is released from the sediment and becomes bioavailable.

To control eutrophication in the nation's waters, the EPA in 1986 determined P should not exceed 0.01 mg P L^{-1} in streams, 0.05 mg P L^{-1} in streams entering reservoirs, and 0.025 mg P L^{-1} in reservoirs. Anderson et al. (2002) stated that loads of 8 x 10^7 kg yr^{-1} N and 4 x 10^6 kg yr^{-1} P were large enough to cause early spring algal blooms in the Chesapeake Bay. It is important to note the Chesapeake Bay has an estimated turnover rate of 35 d and mean depth of 9 m. The Neuse estuary has a turnover rate of 80 d and a mean depth of 3.5 to 4 m. Anderson et al. (2002) pointed out that in such poorly flushed systems, loads of 5 x 10^6 kg yr^{-1} N and 6 to 8 x 10^5 kg yr^{-1} P have been documented to cause large (nontoxic) dinoflagellate blooms. By limiting N and P in waterways, the EPA hopes to curb eutrphication, which can lead to large fish kills. In 1997, the Cheaspeake Basin suffered a massive fish kill, which has been blamed on a high concentration of P in the bay, which allowed a large algal bloom of a dinoflagellate, *Pfisteria piscicidia*.

It has been demonstrated that when grasslands are fertilized with broiler litter, soil test P is not an indicator of P loading during a runoff event. Instead, it has been concluded that the P concentration in runoff is dependent on the amount applied and time that has passed since the broler litter was applied (Pierson et al., 2001). Several best management practices have been studied in the area of manure management with respect to P. The costs of elaborate wetland construction and in stream biochemical filters have prevented many of these methods from being accepted in areas severely impaired by P.

Nitrogen

The average total Kjeldahl N loading from fresh beef manure is 3.4×10^{-4} kg kg^{-1} live animal mass d^{-1} (ASAE, 1998). Of the total Kjeldahl N load, the average ammonia-N load is 8.6×10^{-5} kg kg^{-1} live animal mass d^{-1} (ASAE, 1998).

Nitrogen is found in the environment primarily as dinitrogen gas (N_2), organic N in tissues, ammonium (NH_4^+), and nitrate (NO_3^-) (Myrold, 1999). The conversion between organic and inorganic N is called mineralization and ends with the production of ammonium by soil microbes. Nitrification is the process in which ammonium is converted to nitrate by nitrifying bacteria. Nitrate is very mobile in water, which allows easy uptake of this form of N by plants. Nitrate can easily be leached to groundwater and can cause methemoglobinemia in human infants as well as toxic effects in livestock. Nitrogen is often a limiting factor in algal growth; therefore, if nitrate is leached into surface waters, it can aid in eutrophication. However, the final fate of nitrate is the atmosphere through an anaerobic process called denitrification, which is carried out by aerobic heterotrophic soil bacteria (Myrold, 1999). Denitrifying bacteria carry out nitrate respiration, which allows soils with poor aeration, high concentration of nitrate, and organic matter (such as wetlands) to have high rates of denitrification.

A net balance equation to explain the Nitrogen cycle was proposed by Garten and Ashwood (2003) whereby:

$$X=(I+F+M)-(U+D+V)$$

where X is the potential excess of N for a particular land cover type; I is atmospheric N deposition; F is fertilizer N input; M is the net mineralization; U is plant uptake; D is denitrification; and V is volatilization of N fertilizers.

There are two ways N can be removed via riparian filter strips, plant uptake and denitrification. If surface water is shallow and passes through the root zone, plants can remove nitrate by simple uptake. It is still debated whether denitrification or plant uptake is the major pathway for nitrate removal in filter strips. Regardless of pathway, vegetation is necessary for nitrate removal, whereby N is withdrawn from groundwater via plant uptake and deposited on the surface zone (Lowrance, 1992). Once there, denitrifying bacteria may convert the nitrate to atmospheric N.

Bacteria

Runoff from cattle pastures is a major source of bacteriological contamination in streams. The average total coliform bacteria loading from fresh beef manure is 8.799 $\log_{10}$ CFU kg^{-1} live animal mass d^{-1} (ASAE, 1998). Fecal coliform bacteria loading is 8.447 $\log_{10}$ CFU kg^{-1} live animal mass d^{-1} and the fecal streptoccus bacteria loading is 8.499 $\log_{10}$ CFU kg^{-1} live animal mass d^{-1} (ASAE, 1998). The concentration of E coli is 5.74 $\log_{10}$ CFU g^{-1} wet weight of manure and the concentration of Enterococci is 3.7 $\log_{10}$ CFU g^{-1} wet weight of manure in beef cattle (Jacobson et al., 2002). Because of the danger and difficulty in culturing the entire population of fecal pathogens in contaminated streams, fecal indicator bacteria are used to estimate pathogenic bacteria contamination. Fecal indicator bacteria are non pathogenic; found in the intestines of warm-blooded animals; are present at higher concentrations in intestines than pathogenic species; and do not persist outside the intestinal tract. A positive correlation exists between fecal indicator bacteria levels and the presence of pathogenic bacteria. The most common fecal indicator bacteria discussed in the literature are Total Coliforms, Fecal Anerobes, Fecal Coliforms, and Fecal Enterococci. The EPA recommended the use of *E. coli* as the preferred fecal indicator bacteria in 1986, as *E. coli* is a much more effective predictor of gastrointestinal illness than fecal coliforms. *E. coli* is in the family Enterobacteriaceae and is defined as a fecal coliform that posesses the enzyme B-glucuronidase, which produces fluorogen by cleaving a fluorogenic substrate such as 4-methyl-umbelliferyl-B-D-glucuronide (Clesceri et al, 1998). As the Georgia EPD is expected to begin using *E. coli* as the accepted fecal indicator for fresh water, this literature review will focus on this particular species.

There are four accepted methods for enumerating *E. coli* and determining the level of fecal indicator bacteria in water: multiple tube fermentation, agar (MI), membrane filtration (mTEC), and enzyme substrate (Colilert). Enzyme substrate techniques, such as the Colilert method are recommended for *E. coli* enumeration in drinking water where a sample of water is mixed with a fluorogenic compound and incubated for 24 h at 35 ± 0.5^{o}C. The presence of fluorescence is a positive test for *E. coli* when samples are viewed under a long-wave (366-nm) ultraviolet lamp (Clesceri et al., 1998). The effectiveness of alternative fecal indicator methods has been widely discussed in the literature. To compare the effectiveness of three alternative *E.coli* detection methods (the modified mTEC ,MI, and Colilert) to the traditional approved mTEC method, researchers collected 70 water samples from three Lake Erie public beaches from May to September 1997 and analyzed the samples in the laboratory for *E. coli* (Francy and Darner, 2000). The researchers noted that the major differences in the techniques revolves around the chemical substrate cleaved by *E. coli*. The modified mTEC method uses 5-bromo-6-chloro-3-indolyl-B-D-glucuronide (Magenta Gluc), MI uses indoxyl-B-D-glucuronide (IBDG), and Colilert uses 4-methyl-lumbelliferyl-b-d-glucuronide (MUG). The researchers log10 transformed their data and ran an ANOVA test followed by Tukey-Kramer multiple comparison tests to determine if there were differences in these techniques. They discovered a statistical difference did not exist between between the MI and traditional mTEC method, thus the MI method was the most accurate of the three techniques when compared to the mTEC. However, a statistical difference exists between the modified mTEC or Colilert and the traditional mTEC method. Finally, the researchers noted that the Colilert method was effective in assessing the low and middle ranges of bacteria, but the false negative rate was greater than 5% (Francy and Darner, 2000).

EPA TMDLs will be established based on a 30-day geometric mean density and a maximum single sample. The EPA is recommending that at 8 illnesses per 1000 people, the Geometric mean Density of *E. coli* should not exceed 126 cfu/100 mL. Furthermore, the single sample maximum concentration of E. coli in designated beach areas is 235 cfu/100 mL and 576 cfu/100 mL in infrequently used full body contact waters (USEPA, 2002).

Runoff from grazed pastures may contaminate surface waters with pathogenic bacteria. Three years of runoff were collected and analyzed for fecal coliform and fecal streptococcus (Edwards et al., 1997). Runoff concentrations exceeded the primary contact standard 87% of the time and exceeded the secondary contact standard in 70% of the runoff events. Fecal Coliform and Fecal Streptococci contamination levels were significantly affected by seasonal variations with the highest concentrations of these bacterial contaminants being observed in warmer months, which could be due to bacterial regrowth (Skinner et al., 1974, Jawson et al., 1982, and Tiedemann et al., 1988).

Sediment

By far in terms of volume, suspended sediment is the largest contaminant in surface waters (Cooper, 1993). Erosion is a natural process, but can be sped up by agriculture and construction practices. Many deleterious row-cropping practices have been replaced with best management practices, and a decrease in overall sedimentation has been reported (Wagner, 1999). Sediment can come from upland soils, or from the channel itself. Upland sediment is created when physical breakdown of soil structure occurs at the soil-air interface, creating loose soil particles, thus when a rain event occurs, the dislocated soil particles are suspended in runoff and carried to the stream. Sediment from the stream channel is caused by sloughing of stream bank material which occurs naturally as the stream migrates, but can be worsened by livestock. Historical sedimentation in Georgia surface waters caused by cotton row cropping during the 1800's to 1940's is still considered a major source of current water contamination. Many scientists have suggested it will take hundreds, possibly thousands of years before the cotton-era sediments are washed out of Georgia's surface waters.

The effect of sediment on the environment is multi-faceted. Municipal water treatment plants must remove sediment through an expensive filtering system before water can be treated and pumped to the homes of their customers. Due to the high surface area and charge of clay and silt particles, sediment can serve as a transportation agent for bacteria, nutrients, heavy metals, and other contaminants. By having a vehicle for movement through the watershed, contaminants are made more mobile and spread rapidly at high concentration through surface waters. When sediment with a large amount of sorbed P, for example, reaches a reservoir, the P can be released and contribute to eutrophication. Sediment-bound bacteria can represent a considerable fraction of bacteria populations in a waterway (Solo-Gabriele et al., 2000), (Desmarais et al., 2002).

Wood and Armitage (1997) concluded that as primary producers are the base of the food chain, the impact of sediment on these periphyton and aquatic macrophytes can be seen throughout the entire food web. Sediment affects primary producers in four ways: reducing photosynthesis due to decreased light penetration; reducing organic content in periphyton cells; abrasional damage to macrophyte tissue; and preventing algal cell attachment (Wood and Armitage, 1997). Benthic macroinvertebrates are affected by sediment in four ways as well: by altering stream bottom substrate, thus making the stream inhabitable for some species; by increasing drift due to unstable stream bottoms; decreasing respiration by clogging of respiratory organs; by impeding feeding ability of filter feeders reducing the food value of periphyton (Wood and Armitage, 1997). As sediment affects the lower tiers of the aquatic food web, aquatic vertebrates are affected by sediment as well. Wood and Armitage (1997) suggest fish are affected by sediment in five ways: clogging of gill rakers or filaments; reducing spawning habitat; modifying migration patterns; reducing food by reducing primary producers; and reducing the hunting ability of fish, especially in fish that hunt primarily by sight.

Riparian Vegetation

Much debate has been devoted to the type of vegetation in riparian areas. The major focus is on native versus non-native vegetation in the riparian filter strip. Non-native vegetation is often discouraged and viewed as a nuisance even though it can serve as an effective buffer. In the stream bioassessment protocol developed by the USEPA, riparian areas with non-native vegetation are given a lower score than riparian areas composed of native vegetation (Barbour et al., 1999). In the Piedmont, Japanese privet (*Ligustrum japonicum*) and Japanese honeysuckle (*Lonicera japonica*) have become exceedingly well established and have out-competed many of the native plants that were dominant riparian species prior to the importation of these exotics. Unfortunately, there have been no studies examining the filtration of native versus non-native vegetation in Piedmont riparian areas. The major case for encouraging native vegetation in riparian areas is to encourage native wildlife colonization of the riparian area. However, wildlife can have an unexpected negative impact on the riparian area. Opperman and Merenlender (2000) found that deer herbivory on woody riparian species drastically retards the rate of recovery of woody riparian species within degraded riparian corridors. Therefore, not only may farmers need to fence to keep the cattle from feeding on the riparian vegetation, they may also need to build fences to keep the deer from destroying riparian areas. Shields et al. (1995), while working in northwest Mississippi, stated that “the exotic vine kudzu presents perhaps the greatest long-term obstacle to restoring stable, functional riparian areas along incised channels in our region.”

Another debate in riparian vegetation is whether to plant trees, bushes, or grasses. On the recommendation of the North Carolina Division of Forest Resources, Line et al. (2000) created a riparian area by planting hard and softwood trees. After planting the riparian area, a considerable amount of volunteer vegetation such as willows, cattails, weeds, and grasses colonized the area. It was unclear if the weeds and grasses were native to the area. Hubbard and Lowrance (1994) suggested that riparian areas are most effective when three areas are built consecutively upslope from one other. Area 1, closest to the stream, should consist of permanent hardwood trees, which would provide shading, streambank stabilization, and organic debris input. Area 2 should be an area dominated by timber pine species, where maximum biomass production is achieved. Area 3 should be a grass buffer strip that would filter coarse sediment and retard the formation of rills by spreading runoff to the entire landscape.

A lot of discussion has focused on the age of a riparian area to its effectiveness as a filter. Groffman et al. (1991) examined the denitrification rates between grasses and trees and discovered that in a grass riparian area, the denitrification rate cound be as much as 15 kg N ha^{-1}. These data were collected using soil cores instead of field measurements, so caution must be used when interpreting the results. Interestingly, forest plots had lower denitrification rates than the grass riparian area. The lower denitrification rate in the forest plots may be due to the lower pH of the forest soils (<4.5) compared to the higher pH of the grassy plots (5.9) (Groffman et al., 1991). The rate of denitrification depends on substrate availability and anaerobic conditions. Runoff high in C may be more amenable to denitrification in riparian filter strips than runoff with low C concentration (Groffman et al., 1991).

Stream Fencing

Complete cattle exclusion from riparian areas can only be maintained long-term by fencing. Fencing can be cost prohibitive to many farmers, but fencing has been shown to have great impact on improving water quality in streams. Fencing streams restricts cattle access from the riparian areas and prevents access to the streambank, thus preventing the mechanical breakdown of the bank by cattle hooves. By planting trees and excluding dairy cattle access to a 335-m long and 10–16-m wide riparian corridor along a North Carolina stream, Line et. al (2000) significantly ($P<0.05$) reduced weekly total Kjeldahl N, total P, total suspended solids, and total solids loads by 79, 76, 82, and 82%, respectively. They also were able to reduce nitrate+nitrite by 33%, but these data were not significant ($P<0.05$). The researchers speculated the rate of nitrate and nitrite filtration will increase as the trees become established and denitrification increases. By planting trees and excluding cattle access, larger roots developed in the riparian vegetation, which led to more pore space, a higher hydraulic conductivity, and an increase in infiltration.

The adverse effects of cattle on grassland streams is well documented (Belsky et al., 1999). Owens et. al, (1996) investigated the difference in soil loss from year-round grazed unfertilized pastures with fenced and unfenced stream reaches. They found that because the fence prevented mechanical breakdown of the stream banks and the vegetative riparian area retained runoff sediment, the annual sediment concentration in the stream decreased more than 50% after being fenced. The amount of soil lost from the pastures after fencing decreased from 2.5 to 1.4 Mg ha^{-1}, a 40% reduction.

Water Troughs

The cost associated with fencing entire reaches of stream riparian areas prevents many farmers from building riparian areas. An alternative to fencing may be off-stream watering sources. Cattle go to the stream to drink and to cool down. The presence of an alternative watering source for cattle reduced the amount of time cattle spent in the stream by 51% (Sheffield et al., 1997). Also, cattle prefer to drink from a spring-fed watering trough 92% more than the stream. Because the cattle were not spending as much time in the stream, stream bank erosion, total suspended solids, total N, ammonium, sediment bound N, total P, and sediment-bound P decreased 77, 90, 54, 70, 68, 81, and 75%, respectively. Concentrations of nitrate and orthophosphorus did not decrease with the installation of an alternative watering source (Sheffield et al., 1997). Numbers of fecal coliform and fecal streptococci also decreased by 51% and 77% respectively.

Oftentimes in considering water quality impacts, small non-commercial animal enterprises (SCAEs) are often overlooked. These operations often attempt to raise a large number of animals on small areas of land, so the contamination from SCAEs can be great. As Atlanta encroaches into the surrounding rural areas of the Georiga Piedmont, large farms are subdivided and turned into SCAEs. Oftentimes, the new farmers do not realize the contamination potential their few animals can pose on their watershed. Alternative watering sources for SCAEs decrease the amount of time cattle spend in the stream to 15 min per day (Godwin and Miner, 1996). Instead of installing expensive and elaborate watering troughs, a cost efficient animal-operated diaphragm pump is installed that allows cattle access to water whenever the animal is thirsty. Even so, many SCAE farmers worry about the ability of cattle to actually operate the pasture pump. The researchers showed that in a 2.4-ha (6 acre) pasture with 27 Holstein heifers, the average water consumption from the pasture pump was higher than the water consumption from a watering trough. Additionally, the learning period for the heifers to use the pasture pump was less than one day (Godwin and Miner, 1996).

Based on the Sheffield et al. (1997) study, one could assume that streambank morphology would be improved with an alternative watering source. However, McInnis and McIver (2001) discovered alternative watering sources had no significant ($p<0.05$) effect on the rate of potential accelerated streambank erosion. To determine this, they calculated an erosion index by assigning a numerical score to each cover/stability class: covered/stable=1; uncovered/stable or covered/unstable=2; and uncovered/unstable=3.

$$\text{Erosion Index}=(1Xn_1)+(2Xn_2)+(3Xn_3)/N_{\text{total}}$$

where $n_{1\text{-}3}$ = number of plots with erosion index 1-3, respectively and n=total number of plots. Cattle grazing resulted in a decline in streambank stability, a decline in the covered/stable streambank class, and an increase in soil erosion. However, in the pastures containing an alternative watering source, the cattle were drawn away from the stream which significantly ($p<0.05$) reduced the development of uncovered/unstable streambanks from 9% in non-supplemented pastures to 3%. Although watering troughs have been shown to have a positive influence on water quality, it has been suggested they may also serve as an ecological reservoir for pathogenic fecal bacteria (LeJeune et al., 2001).

Tracking cattle behavior

The monitoring of cattle behavior in pastures has long been of interest to scientists, and the methods used reflect the evolution of technology. From 1960 to the early 1990's visual observations were used to determine cattle movements (Hull et al., 1960, Hart et al., 1993, Langbein and Nichelmann, 1993, and Smith et al., 1992).

Marlow and Pogacnik (1986) discuss cattle movements in terms of resting and feeding patterns in riparian areas in MT. To collect data, the researchers observed cattle twice a week for 24 h every week in 1982 and 1983, yielding 32 observational periods per year. The researchers concluded that the time cattle in MT spend in the riparian area follows a seasonal trend, as cattle spend more time in the riparian area during the months of July to Oct. The researchers noted this trend could be explained by forage quality being higher in the riparian area. The researchers concluded cattle did not spend a significant amount of time resting in the riparian area in the summer, as presence of face flies caused the cattle to only enter the riparian area at night.

Gary et al. (1983) visually estimated that cattle in central Colorado spend 65% of the day within 100 m of streams, but spend only 5% of their time in the stream. In this study, the researchers observed cows at 5 min intervals between the hours of 7:00 am and 6:00 pm between May and June, 1978 and again in July, 1979. They concluded that cattle grazing had minor effects on water quality with respect to suspended solids, nitrate, and ammonia (Gary et al., 1983).

In 1998, Very High Frequency (VHF) technology was used to measure cattle movements in feedlots (Gibb et al., 1998). It has been demonstrated in the literature that VHF technology is very prone to error in that the amount of error can be greater than 500 m (Rodgers et al. 1996).

The Global Positioning System (GPS) provides much greater accuracy and is now becoming the standard in animal tracking. It operates using 24 US Department of Defense satellites arranged in orbit so that 5 to 8 satellites are visible at any given time over a given location. The satellites transmit a radio signal at 1575.42 MHz in the UHF band. This signal contains several pieces of information: the transmitting satellite's number, information about the status of the satellite, the current date and time, and where each GPS satellite should be at any given time. To determine a given location, GPS receivers compare the time the signal was sent by the satellite with the time the signal was received. Because the velocity of the signal is known, the change in time can be used to calculate distance. By knowing the distance from at least three satellites, GPS receivers triangulate the longitude and latitude of any location. By receiving data from at least four satellites, a GPS receiver can triangulate longitude, latitude, and altitude of any location. The accuracy of GPS receivers is partially controlled by the Department of Defense, with hand-held GPS receivers being accurate up to 15 m. By using the U.S. Coast Guard's differential correction service, sub-meter GPS accuracy is possible, though the high cost of such equipment prevents such technology from being used extensively in animal tracking.

Using GPS to track the movements of cattle has just recently become an option. In 1999, Bailey concluded that the distance cattle will travel from water varies depending on cattle breed. In this study, the researcher stated Charolais-sired first-calf heifers traveled further from water than did Angus-sired heifers. And Tarentaise cattle used steeper slopes and higher terrain than the Hereford cattle. In warmer climates, Brahman cattle tend to travel the greatest distance from water. Bailey (1999) concluded that individual animal performance such as social-rank and lactation can significantly affect the distance cattle travel from water.

Lotek Engineering Inc. (Canada) now manufactures collars that weigh less than 1 kg and are accurate to within 5 m. Turner et al. (2000) used Lotek GPS collars with dual axis motion sensors to study the movement of grazing beef cattle in endophyte-infected pastures in KY. The researchers used the collars to collect data on cattle position in Nov. 1997, May 1998, and Sept. 1998. The purpose of the study was to interpret animal forage utilization with respect to grazing location in a pasture by determining the precise time and location a cow exhibited grazing behavior. The researchers were able to demonstrate definite grazing preferences in cattle and further were able to determine that grazing behavior is influenced greatly by ambient temperature (Turner et al., 2000).

Ganskopp et al. (2000) utilized GPS and geographic information system (GIS) technology to study the grazing behavior of cattle in open-range systems with slopes between 20 and 40%. The goal of this research was to determine if the paths cattle took were dependent on the terrain of their grazing range. Cattle paths were surveyed using a Trimble GPS unit and were overlayed on a digital elevation model (DEM). It was determined that as expected, cattle take the path of least resistance through their grazing range. The researchers concluded cattle preferred to graze on slopes < 9%, but more importantly, cattle established one-way trails to and from watering sources indicating a circular grazing pattern. Although this research is not totally applicable to the Piedmont because Piedmont slopes rarely exceed 15%, it is interesting to note the one-way paths leading from watering troughs left the trough and descended a steep 20 to 40% slope into a lower pasture. Cattle would return to the watering trough by a longer, but less steep path. The implication of this conclusion is the placement of watering troughs may limit or expand the forage utilization in Piedmont pastures.

The amount of time cattle spend in the stream is an important factor in modeling contaminant loads in watershed models, though the current body of literature is inconclusive in this area. The EPA has designed a Bacterial Indicator Tool to aid in fecal bacteria modeling in its BASINS-HSPF model (USEPA, 2000a). This tool has a component that includes the influence of cattle spending time in streams on predicting bacteria loads in surface waters. The model is very sensitive to this parameter; however, the default values the EPA's model uses indicates the percentage of time cattle spend in streams is: 0% for Dec., Jan., Feb., and Mar.; 33% for Apr., May, Sept., and Oct.; and 50% for June, July, and Aug. (USEPA, 2000b).

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CHAPTER 2

CATTLE USE OF RIPARIAN AREAS IN THE GEORGIA PIEDMONT, USA

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Abstract

We used GPS collars to monitor cattle use of the riparian area, riparian shade, and non-riparian shade in three pastures with unfenced streams in Georgia, USA. Cattle spent between 5 and 10% of the day in the riparian area during warm months and less time during cold months, indicating their response, was in part a function of a temperature-humidity index (THI), and we found that when available, cattle preferentially sought shade when they used the riparian area. Cattle spent the maximum amount of time in the riparian area between the hours of 11:00 am and 1:00 pm. There was a linear relationship between cattle use of the riparian area and hourly THI between 5:00 am and 1:00 pm. The amount of time cattle spent in the riparian area was decreased by the presence of non-riparian shade and alternative water sources; therefore, these may be two possible BMPs that could lessen the impact of grazing cattle on surface water quality.

Introduction

Surface runoff from cattle pastures is a major contributor to nonpoint source contamination (Belsky et al., 1999, Line et al., 2000). Contaminants such as N, P, and bacteria from animal grazing can enter streams and cause eutrophication or impose health risks to organisms on a basin-wide scale. Livestock grazing also affects stream hydrology, stream morphology, and soil properties as well as vegetation living by or in streams (Belsky et al., 1999). Therefore, determining the amount of time cattle spend in riparian areas is important to understand the overall impact of cattle on streams.

The current body of literature on cattle time in streams is limited. Working in Montana, Marlow and Pogacnik (1986) concluded that the time cattle spend in the riparian area follows a seasonal trend, spending the most amount of time (44%) grazing the riparian area between Aug. and Sept. Gary (1983) visually estimated that cattle in central Colorado spend 65% of the day within 100 m of streams, but spend only 5% of their time in the stream.

The monitoring of cattle behavior in pastures has long been of interest to scientists, and the methods used reflect the evolution of technology. From 1960 to the early 1990's visual observations were used to determine cattle movements (Hull et al., 1960, Gary 1983, Marlow and Pogacnik, 1986, Hart et al., 1993, Langbein and Nichelmann, 1993, and Smith et al., 1992). In the late 1990's, Very High Frequency (VHF) telemetry was used to monitor cattle behavior in feedlots (Gibb et al., 1998). Nowadays, the Global Positioning System (GPS) provides much greater accuracy than previous methods and is quickly becoming the standard in cattle behavior studies (Bailey 1999, Turner et al., 2000, Ganskopp et al., 2000, and Bicudo et al., 2003)

The objective of this study was to determine the amounts of time cattle spend in riparian areas at different times of the year and to determine the peak hours in which cattle are most likely to utilize the riparian area. A secondary objective was to evaluate the effect of water troughs and non-riparian tree-shaded areas on the time cattle spend in the stream.

Materials and Methods

Site Description

The pastures used for this study (G2, G5, G8; Fig 2.1) were located at the Central Research and Education Center of the University of Georgia (Eatonton, GA; Latitude 33°24' N, Longitude 83°29' W, elevation 150 m). The two predominant forage species in the three pastures were 95% wild type endophyte-infected (*Neotyphodium coenophialum* Morgan-Jones and Gams) tall fescue (*Festuca arundinacea* Schreb.) and bermudagrass (*Cynodon dactylon* L.). The soils have been classified as Iredell sandy loam (Fine, montmorillonitic, thermic, Typic Hapudalfs); Mecklenburg sandy loam and sandy clay loam (Fine, mixed thermic Ultic Hapludalfs); Chewacla silty clay (Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts); and Wehadkee silty clay loam (Fine-loamy, mixed, active, nonacid, thermic Fluvaquentic Endoaquepts) (Perkins et al., 1987).

The riparian areas of pastures G5 and G8 had been unfenced for over 10 yr. It is important to note that the streams in G5 and G8 were dredged in 1994 to improve pasture drainage. The riparian area in G2 was completely fenced prior to April 24, 2003, at which time 5.5-m gaps were cut in both sides of the stream fence at each end of the pasture, thus allowing cattle access to the riparian area.

The pastures were stocked with 20 cow-calf pairs per pasture. Single strand, electric cross fences were installed before the project began, and were used to rotationally graze cattle on either side of the riparian area; however, cattle were allowed access to the entire riparian area throughout the duration of the study. CowCalf5 (University of Nebraska-Lincoln Great Plains Veterinary Educational Center, Clay Center, NE) was used to determine the 205-d average daily gain (ADG) of calves born and weaned in pastures G5 and G8 during 2002 and 2003.

Two water troughs with water meters were installed in each pasture before the project began. Water meters were read weekly or biweekly during 36 measurement periods between May 2001 and January 2004, and readings were used to determine daily water consumption per cow/calf pair. Water meters were also installed in two pastures located upstream of the ones used in the study, where the streams were fenced to prevent cattle access. These pastures were of similar area as those in the study and were also stocked with 20 cow-calf pairs. For each measurement period, the amount of water consumed by cattle in the study pastures (where cattle had access to the streams) was subtracted from the amount of water consumed in the upstream pastures (where cattle did not have access to the streams) to obtain an estimate of the amount of water that cattle were drinking from the stream when water troughs were available. Also, for each measurement period, the amount of water consumed in G5 was subtracted from the amount of water subtracted in G8 to evaluate differences between pastures. All of these differences were evaluated by a t--test to determine if they were significant different from zero ($p<0.05$). The average distance from the water troughs to the stream was 147 m in G2, 91 m in G5 and 81 m in

G8. Monitoring of cattle behavior and location with GPS collars took place both when troughs were available and not available (Table 2.1). When the water troughs were not available, an electric fence around the water trough prevented cattle access.

Shade and riparian area survey

The riparian area in pastures G5 and G8 were not easily identifiable because tall fescue had encroached to the edge of the water; thereby masking a clear vegetation change. Therefore, to delineate the riparian area, the banks of the two streams were surveyed using a submeter Leica 342 GPS unit (Leica Geosystems AG, Switzerland), and a 12-m buffer area centered on the stream was created in ArcView GIS 3.2 (Environmental Systems Research Institute, Inc., Redlands, CA). To delineate the extent of the tree shade, the crown diameter of each tree was surveyed with a submeter Trimble Model TSC1 GPS unit (Trimble, Sunnyvale, CA) after leaf-out, and a 6-m buffer around the edge of the crown was created in ArcView GIS 3.2 using the Spatial Analyst (Environmental Systems Research Institute, Inc., Redlands, CA) and the Xtoolsmh extensions (Oregon Department of Forestry, Salem, OR). The submeter Trimble Model TSC1 GPS was also used to delineate pasture, stream, and cross fences as well as determine the position of the water troughs in the three pastures.

GPS collars

At the onset of the project, three Model GPS2200LR Livestock GPS Collars (Lotek Wireless, Inc., Newmarket, Ontario, Canada) were purchased. Additional funding was received after three months, and eight more collars were purchased. Because the collars were programmed to take a location fix every 5 min and the memory could hold about 5,000 data points, each collection period was limited to 17 d.

To test the accuracy of the collars, a benchmark was established adjacent to pasture G2 by georeferencing it with respect to a USGS benchmark. Two GPS Collars were placed on the benchmark for two weeks, after which the data from the collars was differentially corrected using data from a US Coastguard reference station in Macon, GA. Once differentially corrected, 95% of the data points taken by the collars were accurate to within 3 m of the established benchmark.

Angus and Angus-Hereford beef cows (*Bos Taurus*) being used in a water quality study were randomly selected and fitted with GPS collars, after which, they were returned to their respective pastures and allowed to resume normal grazing behavior. Calving and weaning seasons limited the frequency and pasture location in which the collars were used (Table 2.1). Collars were placed on cattle on 5 different dates in pasture G2, 15 different dates in pasture G5, and 16 different dates in pasture G8 (Table 2.1). The total number of cows collared were 27 in pasture G2, 49 in pasture G5, and 47 in pasture G8. The collars were placed on different cattle on each collection period, and at the end of the period, they were removed from the cattle and the data downloaded using Lotek's proprietary software. Data from a US Coastguard reference station in Macon, GA was used to differentially correct the collar data using N4, a proprietary software program from Lotek. Once corrected, the data were reprojected to UTM coordinates using CorpCon version 5.11 (U.S. Army Corps of Engineers, Topographic Engineering Center, Alexandria, VA) and were imported as event themes into ArcView GIS 3.2 (Fig 2.2). The total number of differentially corrected GPS data points gathered and analyzed for this study were 77,518 in pasture G2; 167,641 in pasture G5; and 169,349 in pasture G8.

Statistical Analysis

ArcView GIS was used to identify and export tables of attributes (date, cow number, time, and temperature) of the points gathered from each collar that intersected with either the total riparian area, tree-shaded riparian area, or tree-shaded non-riparian area layers. The tables were then imported into Excel (Microsoft, Redmond, WA) and the attributes were sorted, averaged, and analyzed for several key trends.

Effect of time of year

To determine the amount of time cattle spent in the riparian area and non-riparian shade as a function of month of the year, the data from cow collars used in pastures G5 and G8 were sorted by month, averaged, the standard error determined, and plotted in SigmaPlot Version 8.0 (SPSS Inc., Chicago, IL). PROC MIXED in SAS (SAS Institute Inc., 1999) was used to quantify monthly differences in the cattle usage of the riparian area.

Effect of THI

Valtorta et al. (1997) noted heat dissipation by cattle is a function of radiation, wind speed, air temperature, and humidity; therefore, the Temperature Humidity Index (THI) (National Oceanic and Atmospheric Administration, 1976) was used as a key variable in analyzing cattle behavior. This index is calculated using the daily maximum dry-bulb temperature in Celsius (T) and daily minimum humidity as a percentage (H) whereby:

$$THI= (9/5*T+32)-(.55-(.55(H/100)))*((9/5*T+32)-58).$$

To evaluate the effect of THI on cattle behavior, the THI and amount of time cattle spent in the riparian area were determined on a daily basis for each collaring event that took place in pastures G5 and G8. Then the data were averaged and the standard error determined on a per collar basis, and PROC REG in SAS (SAS Institute Inc., 1999) was used to regress percent time in the riparian area on THI. PROC GLM in SAS was used to test whether the linear regressions were different between pastures G5 and G8. To prevent a confounding effect of the water trough condition, only the data obtained while troughs were available were used in the data analysis.

Effect of time of day

To determine the distribution of hourly use of the riparian area by cattle, the average hourly time cattle spent in the stream was determined in each pasture for two collaring events (8 to 22 November, 2001 ; 17 May to 3 June, 2003). PROC GLM (SAS Institute Inc., 1999) was used to evaluate the effect of hour of the day on percentage of that hour spent in the riparian area. PROC REG (SAS Institute Inc., 1999) was used to evaluate the relationship between hourly THI and percent of hourly time spent in the riparian area.

Effect of water trough

To determine the effect of water trough availability the time cattle spent in the riparian areas and non-riparian shade, data obtained during periods when the condition of the troughs changed over the monitoring period were divided into two groups based on trough status: available or not available. PROC MIXED (SAS Institute Inc., 1999) was then used to determine if water trough availability was a significant factor in affecting percentage of the day cattle spent in the riparian area or in non-riparian shade.

Calf ADG

To evaluate any possible cattle performance differences in pastures with differing amounts of non-riparian shade, PROC GLM (SAS Institute Inc., 1999) was used to analyze the adjusted 205-d ADG based on birth weights and weaning weights of of calves born and weaned in G5 and G8 during 2002 and 2003.

Results and Discussion

The most striking differences among the three pastures were the area and distribution of tree-shade. In all the pastures, the majority of the shade available to cattle was in non-riparian areas, though the amounts of shade varied greatly (Table 2.2, Fig. 2.1). Pasture G2 and G8 had over twice the amount of total shade of pasture G5. Pasture G8 had the largest amount of non-riparian area and total shade; however, pasture G2 had the most riparian shade, as the entire riparian area was shaded. The riparian shade in G2 was present as a result of the riparian area having been fenced for the previous 40 yr, thus allowing large trees to be abundant. Pasture G5 had the smallest amount of riparian and non-riparian shade even though the total pasture area was larger than G8.

Effect of time of year

Figure 2.2 is representative of the data collected and shows the location at 5 min increments of one cow during one 17-d collaring period in G5. In general, cattle in pasture G5 spent significantly ($p<0.05$) more time in the riparian area during warm months (May through Sept.) than during cold months (Nov., Dec., and Mar.) (Fig. 2.3a). The monthly distribution of cattle use of the riparian areas generally appears to be responding to THI (Fig. 2.3a). Cattle in pasture G5 spent the same amount of time in the riparian area (average of 9.2% of the day) during the months of May through Sept. ($p<0.05$), although THI was greater in Sept. This result could have been a response to fescue toxicosis, which usually peaks in May through June. Whittier (1993) suggested that when calculating THI, it would be necessary to add 2 to 4 ^{o}C to the outside temperature to correct for the effect of fescue toxicosis in cattle. Therefore, at a given humidity and temperature, cattle grazing endophyte-infected fescue would be responding to a greater THI than cattle grazing other forages. Cattle in G8 showed a similar trend as those in G5, but because of the large variability, differences between warm and cold months were only significant at $p= 0.17$. Similar results were obtained while water troughs were not available (data not shown).

In pasture G5, when cattle were in riparian areas during months between leaf-out and fall, they spent an average of 92% of the time in shaded areas. In pasture G8, cattle spent an average of 81% of the time in riparian area in the tree-shade. It can be concluded from these results that cattle utilized the riparian areas not only for water, but for shade as well.

On average cattle in pasture G5 spent more time in the riparian area than cattle in pasture G8 from May through Sept. This is probably due to the smaller amount of non-riparian shade in pasture G5 (6425 m^3) than in pasture G8 (18,523 m^3). In fact, during May, June, and July, cattle in G5 spent less time in the non-riparian shade than cattle in G8 (Fig 2.3b). Although cattle behavior was different between both pastures, the ADG of calves was not significantly ($p= 0.77$) different between the pastures (1.005 kg in G5 and 0.995 kg in G8). These results suggest that abundant non-riparian shade may decrease the amount of time cattle spend in riparian areas without affecting cattle performance.

The amounts of time cattle spent in the riparian area in this study are less than those found by Marlow and Pognack (1986) in MT. They made hourly observations of four yearling heifers in Aug. and Sept. and determined that cattle rested in the riparian area for 44% of the day, which they suspected to be a result of higher forage quality in the riparian area during that time of year. The cattle were grazing more in the riparian area, and when they were ready to rest, they simply remained there rather than resting in other parts of the pasture.

The amount of time cattle spend in streams is an important factor in modeling fecal bacteria loads in watershed models. The EPA has developed a Bacterial Indicator Tool to aid in fecal bacteria modeling in its BASINS-HSPF model (USEPA, 2000a), and one of the most sensitive parameters of the model is the time cattle spend in streams. During Dec. and Mar. the average time cattle spent in the stream in pastures G5 and G8 was slightly greater than the EPA estimated default numbers in the Bacterial Indicator Tool (EPA, 2000b). Cattle in G5 spent 1.5, and 1.4% of the day in the riparian area during Dec. and Mar, respectively, as compared to the default values of 0% in the tool. Cattle in pasture G8 spent slightly more time (4.2, and 1.6% of the day) in riparian areas during Dec. and Mar., which is again larger than the default values in the Bacterial Indicator Tool. However between Apr. and Nov., cattle in pastures G5 and G8 on average spent less time in the riparian area than the default values of the Bacterial indicator tool

(8.1% in G5 and 5.3% in G8 versus 37.4% in the Bacterial Indicator Tool) . The use of less time in the riparian area would decrease the estimated loading rate of fecal bacteria to surface waters as modeled by the EPA's Bacterial Indicator Tool.

Effect of THI

As noted before, data collected during times when water troughs were not available were omitted from this dataset, so as to prevent a possible confounding effect in the analysis. A visual analysis of Fig. 2.4 shows that large values for the percentage of time spent in the riparian areas are observed at THI>72. Dairy cattle are considered to be experiencing stress when the THI is greater than 72 (Armstrong 1994). Data for beef cattle stress based on THI have not been directly published, however a water intake study by Bicudo et al. (2003) showed a sharp increase in water consumption at THI>75.

The response of average percentage daily time spent in the riparian area to average THI was linear and different in pastures G5 and G8 (Fig 2.4.). The significant difference ($p= 0.04$) between the slopes of the two regression lines is probably the result of differences in the amount of non-riparian pasture shade between the two pastures. As mentioned before, the main differences between pastures G5 and G8 were the location and amount of shade available to the cattle. Pasture G8 had over twice the amount of non-riparian shade available to cattle as did pasture G5.

The slope of the regression line for pasture G5 is over twice that of pasture G8 (0.33 vs 0.14). This response translates to cattle in G5 spending 1.5 times the amount of time in the riparian area that cattle in G8 spent at THI = 85 (9.5 % vs 5.9 %). These results suggest that a valid best management practice (BMP) for a producer might be to encourage or build shade in non-riparian areas.

Effect of time of day

Knowing the time of the day when cattle are in riparian areas could be helpful to plan baseflow sampling times. Producer observations have for many years supported the idea that cattle use of the riparian area follows a daily pattern; therefore, to quantify these observations, the average hourly distribution of THI and time cattle spent in the riparian area was determined. A collaring event when water troughs were available in pastures G5 and G8 was analyzed on an hourly basis between 8 through 22 November, 2001 (Fig. 2.5). In pasture G5, the time cattle spent in the riparian area did not respond to THI in a linear fashion during the hours of 5:00 am and 1:00 pm ($r^2 = 0.28$); however, it did respond more linearly to THI during the hours of 1:00 pm and 9:00 pm ($r^2 = 0.51$). Cattle in G5 spent the maximum percentage of hourly time in the riparian area (17%) between 4:00 pm and 5:00 pm and spent significantly ($p<0.01$) less time in the riparian area for the remaining 23 h of the day. Cattle in G8 responded somewhat linearly to THI between 5:00 am and 1:00 pm ($r^2 = 0.43$) and between 1:00 pm to 9:00 pm ($r^2 = 0.40$). Cattle in G8 spent the maximum percentage of hourly time (18%) in the riparian area between 1:00 pm and 2:00 pm and spent significantly ($p< 0.01$) less time in the riparian area for 18 h a day.

Between 17 May and 3 June, 2003, hourly cattle time in the riparian area was analyzed for pastures G2, G5, and G8 when the water troughs were not available (Fig. 2.6). In pastures G2 and G8, the time spent in the riparian area seems to be a direct response to THI between 5:00 am and 1:00 pm ($r^2 = 0.71$ in pasture G2; $r^2 = 0.88$ in pasture G8). The time spent by cattle in the riparian area of pasture G5 did not seem to respond directly to THI between the hours of 5:00 am and 1:00 pm ($r^2= 0.29$). It is surprising, however, that in all three pastures cattle spent the maximum amount of time in the riparian area between the hours of 11:00 am and 1:00 pm ($p< 0.01$), not during the peak THI, which occurred between the hours of 2:00 pm and 5:00

pm. Thus, the time spent by cattle in the riparian areas to THI was not as strong between the hours of 1:00 pm and 9:00 pm as between the hours of 5:00 am and 1:00 pm (r^2 values for the pastures are 0.17 in pasture G2, 0.41 in pasture G5, and 0.30 in pasture G8). This pattern may be due to foraging or to alkaloid presence in tall fescue. Ergot alkaloids produced by the endophyte in tall fescue have been shown to induce vascular constriction and therefore cause hyperthermia in cattle (Hoveland, 2003). It is possible then that cattle in the three pastures grazed fescue early in the morning and sought shade time as they were undergoing alkaloid stress. Marlow and Pogacnik (1986) noted similar grazing patterns in Montana (forages not exactly known) in that cattle grazed from 5:00 am to 9:00 am, rested and ruminated from 9:00 am to 3:00 pm, grazed again from 3:00 pm to 10:00 pm, and rested from 10:00 pm to 5:00 am.

Effect of water trough

In Mar and Dec. 2002, cattle in pastures G5 and G8 were monitored for at least 6 d with while troughs were available, followed by at least 7 d with troughs not available (Table 2.3). It is important to note the water troughs had been available prior to the study, thus cattle had become accustomed to drinking at these locations. This experiment therefore monitored the initial reaction of cattle being forced to drink from the stream. In terms of apparent water consumption, cattle in pastures G5 and G8 were drinking an average of 40.1 L animal^{-1} day^{-1} in March 2002 and 27.6 L animal^{-1} day^{-1} in Dec. 2002 while water troughs were available. Therefore, while the troughs were not available, cattle daily water demands had to be satisfied by the stream.

The average, daily consumption of water from the water trough was 42.1 L per cow/calf pair in pasture G5 and 37.7 L per cow/calf pair in pasture G8 (Table 2.3). In contrast, the average, daily consumption of water in pastures with fenced streams was 56.2 L per cow/calf for the pasture upstream of G5 and 55.0 L per cow/calf pair in the pasture upstream of G8. Assuming that the water requirements by cattle were similar in pastures with fenced and unfenced streams, these results suggest that the average daily consumption of water from the stream was 14.2 L per cow/calf pair in pasture G5 (25% of total consumption) and 17.3 L per cow/calf pair (31 % of total consumption) in pasture G8 (Table 2.3) . Both of these values were significantly different from zero ($p<0.001$). Thus, when water troughs were available, cattle were still drinking water from the stream, although most of their water was obtained from the troughs.

Analysis of the differences between pastures G5 and G8 in the daily consumption of water from water troughs indicated that on average, cattle in pasture G5 consumed 4.3 L more per cow/calf pair than cattle in pasture G8 ($p<0.05$). The larger water consumption in pasture G5 may have been due to the smaller amount of non-riparian shade in that pasture.

When the water troughs were available and then made not available in pastures G5 and G8, the cattle significantly increased ($p<0.01$) the amount of time spent in the riparian area in G5 but not in G8 (Table 2.4 Fig. 2.7).

By examining the percentage of time cattle spent in the non-riparian shade, it is possible to explain why cattle use of the riparian area in G8 did not significantly respond to trough condition. While the water trough was available March, cattle in G8 spent an average of 49% of the day in non-riparian shade (Table 2.4). Cattle in this pasture appeared to prefer the large area (5,419 m^2) of shade near the North corner of the pasture, probably because this shade is in close proximity (28 m) to the water trough. Riparian use was relatively low (1.6%) when the water trough was available, as cattle preferred to drink from the water trough and quickly return to the shade. When the trough was not available and cattle were forced to drink from the stream, they decreased the use of non-riparian shade from 49% to 36% ($p < 0.01$), but since their use of the riparian area did not increase significantly, they must have increased the time spent in the open pasture, most likely walking to and from their preferred non-riparian area tree shade and the stream to drink. Without data from motion sensors, it is difficult to conclude that cattle were grazing more, but it is clear they were spending more time in the open pasture.

In March, cattle in G5 spent on average 1.9 % of the day in the non-riparian shade when the water trough was available (Table 2.4). When the trough was not available, cattle spent 6.5% of the day in the non-riparian shade, which is the opposite trend noted in pasture G8. This response is due to the fact that while the water trough was not available, cattle must get their water from the stream. In pasture G5, 67% of the non-riparian shade was within 25 m of the riparian area (Fig. 2.1). The next closest shade was 102 m from the riparian area; therefore, not wanting to travel far from water, cattle increased the rate at which they used the riparian and non-riparian shade near the riparian area while water troughs were not available.

Similar results to those obtained in March were observed in Dec. 2002, although at that time leaves were not on the trees (Table 2.3). The lack of an increase in the use of the riparian area in G8 when the trough was not available in Dec 2002 may be explained similarly as in March 2002. Although leaves were not on the trees in Dec, cattle in G8 had a preference for resting in the large area of non-riparian shade in the northern corner of the pasture.

In 2004, a similar experiment was conducted in G2 to determine if cattle would behave similarly to cattle in pastures G5 and G8. It is interesting to note what appears to be a cyclic pattern of cattle use of the riparian area while the water troughs were available (Fig. 2.8). Cattle broke the electric fence surrounding the water trough 5 d (c5) after the trough was available, and the fence was repaired 2 d later (c7). Even though cattle gained access to the water trough for 2 d, with an available water trough cattle spent 11.4% of the day in the riparian area as compared to 16.1 % when the trough was not available, a significant increase ($p < 0.01$).

In July 2003, another experiment was conducted in pastures G5 and G8 with a reversal of the water trough availability (Fig. 2.9). Cattle were monitored for 7 d while water troughs were not available trough followed by at least 10 d with available troughs. Cattle significantly decreased the amount of time they spent in the riparian area in G5 when the water trough was made available (Table 2.4). When the water trough was available cattle in pasture G8 significantly ($p< 0.01$) increased the time they spent in the non-riparian shade from 19% to 27%

of the day (Table 2.4); however, an available water trough did not significantly alter cattle use of the riparian area. These figures reflect the fact cattle were still remaining in the open pasture for large portions of the day. Non-riparian shade use in pasture G5 tended to decrease ($p= 0.08$) from an average of 5.2% when the trough was not available to 3.9% of the day when the water trough was available.

Providing a water trough significantly reduced the time cattle spent in the riparian zone in G5 by 72.3% in March and 39.81% in July. In VA, Sheffield et al. (1997) noted a similar trend in riparian use when 5- min observations were taken of Angus x Hereford or Angus x Brahman cross cattle between daybreak and dark. They discovered that before water troughs were installed, cattle spent an average of 12.69 min cow^{-1} day^{-1} in the stream area. This amount was reduced to 6.19 min cow^{-1} day^{-1} after the installation of a water trough, a 51.2 % reduction. The researchers further noted that when given the option, cattle preferred to drink from the water troughs 92% of the time more than drinking from the stream. Godwin and Miner (1996) observing four beef cattle in Oregon between 7 Aug and 18 Sept 1993 noted a 75% reduction in the time cattle spent in the stream after the installation of a water trough.

With respect to water consumption, when the water troughs were made available again in pastures G5 and G8, cattle quickly began drinking at an average rate of 34.3 L animal^{-1} day^{-1}. This indicates that cattle readily will return to the water trough and might indicate cattle prefer to drink from troughs to the stream when given the option.

Summary and Conclusions

Cattle with access to a water trough spent between 5 and 10% of the day in the riparian area during warm months (May through Sept.) and less time during cold months, indicating their response, was in part a function of monthly THI. Between 81% and 92% of the time spent in the riparian area was in the shade. Cattle spent the maximum amount of time in the riparian area between the hours of 11:00 am and 1:00 pm. There was a linear relationship between cattle use of the riparian area and hourly THI between 5:00 am 1:00 pm. However, after 1:00 pm, cattle use of the riparian area ceased to respond linearly to hourly THI. Cattle spent more time in the riparain area in the pasture with the least amount of non-riparian shade, and in this pasture the availability of a water trough reduced the amount of time cattle were in the riparain area. Cattle response to alternative water sources and to non-riparian shade suggests these may be two possible BMPs that could lessen the impact of grazing cattle on surface water quality. A variable that may have affected significantly our results is the presence of endophyte-infected tall fescue. As this forage has been shown to increase the core body temperature of mammals, the level of endophyte infection in a pasture could be a major factor in the amount of time cattle spend in riparian areas attempting to maintain homeostasis by cooling in water. Therefore, different results may be obtained in endophyte-free or novel endophyte-infected tall fescue.

Acknowledgements

The authors would like to thank the entire staff of the Central Research and Education Center for their help in this study. Specifically, the authors would like to acknowledge Tom Fitzgerald, Chad Westmoreland, Frank Newsome, Gerald Cathey, Timothy Hunnicutt, Johnnie Hash, and Eric Brazil for their assistance in maintaining a healthy grazing system and herd of cattle, for their expertise and assistance in handling and collaring the cows, and for taking water meter readings. The authors would like to also like to express their gratitude to the National Resources Conservation Service for their financial support of this project. Finally, the authors would like to thank Dr. Glenn Ware for his expertise and assistance in analyzing such an immense amount of data.

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Table 2.1. Start dates for 17-d, GPS collar measurement periods in three pastures.

Pasture	Start Date	Number of Collars	Watering Trough Condition
G2	29 May 2003	4	Available
G2	30 Jun 2003	4	Available
G2	21 Jul 2003	4	Available
G2	26 Aug 2003	4	Available
G2	27 Apr 2004	11	Available then Not Available
G5	8 May 2001	3	Available
G5	7 Jun 2001	3	Available
G5	5 Jul 2001	3	Available
G5	2 Aug 2001	3	Available
G5	8 Nov 2001	3	Available
G5	18 Dec 2001	2	Available
G5	8 Mar 2002	3	Available then Not Available
G5	29 Mar 2002	3	Not Available
G5	22 Apr 2002	3	Not Available
G5	13 May 2002	4	Not Available
G5	16 Dec 2002	5	Available then Not Available
G5	29 May 2003	3	Not Available
G5	30 Jun 2003	4	Not Available
G5	21 Jul 2003	3	Not Available then Available
G5	26 Aug 2003	4	Available
G8	24 Apr 2001	3	Available
G8	24 May 2001	3	Available
G8	21 Jun 2001	3	Available
G8	19 Jul 2001	3	Available
G8	20 Aug 2001	3	Available
G8	8 Nov 2001	2	Available
G8	18 Dec 2001	2	Available
G8	8 Mar 2002	3	Available then Not Available
G8	29 Mar 2002	3	Not Available
G8	22 Apr 2002	2	Not Available
G8	13 May 2002	3	Not Available
G8	16 Dec 2002	3	Available then Not Available
G8	29 May 2003	4	Not Available
G8	30 Jun 2003	3	Not Available
G8	21 Jul 2003	4	Not Available then Available
G8	26 Aug 2003	3	Available

Table 2.2. Tree-shaded area, riparian area, and total area of three pastures

	Pasture		
	G2	G5	G8
		m^2	
Non-riparian area, tree-shaded	17,320	6,425	18,523
Riparian area, tree-shaded	5,664	4,212	5,010
Total area, tree-shaded	22,894	10,637	23,533
Total riparian area	5,664	4,961	6,406
Total pasture area (ha)	19.88	17.52	14.20
		%	
Non-riparian area, tree-shaded (as % of total shade)	75	60	79
Riparian area, tree-shaded (as % of total shade)	25	40	22
Riparian area, tree-shaded (as % of riparian area)	100	85	78

Table 2.3. Yearly average water consumption per cow/calf pair per day when water troughs were available in upstream pastures with fenced (G6 and G9) and in pastures with unfenced (G8 and G5) streams

Pasture	L cow/calf^{-1} d^{-1}	
	Mean	Std Dev
G6 (Upstream of G5)	56.2	21.5
G5	42.1	16.8
G9 (Upstream of G8)	55.0	21.4
G8	37.7	14.7
G6-G5	14.2*	11.5
G9-G8	17.3*	15.9
G5-G8	4.3*	12.5

* Indicates significantly different from zero at $p = 0.05$

Table 2.4. Average percent of daily time spent in the riparian area (PRA) and non-riparian shade (NRS) of three pastures as a function of watering trough condition at these dates.

	Monitoring Start Date				
Trough	6 Mar. 2002		18 Dec. 2002	19 July 2003	
			Pasture G5		
	PRA	NRS	PRA	PRA	NRS
Available	1.2	1.9	0.1	6.5	3.9
Not Available	4.4	6.5	2.4	10.8	5.2
p>F	0.0001	0.0001	0.0001	0.079	0.076
			Pasture G8		
Available	1.6	49	3.8	5.3	27
Not Available	2.0	36	5.7	5.6	19
p>F	0.47	0.0001	0.21	0.79	0.0001

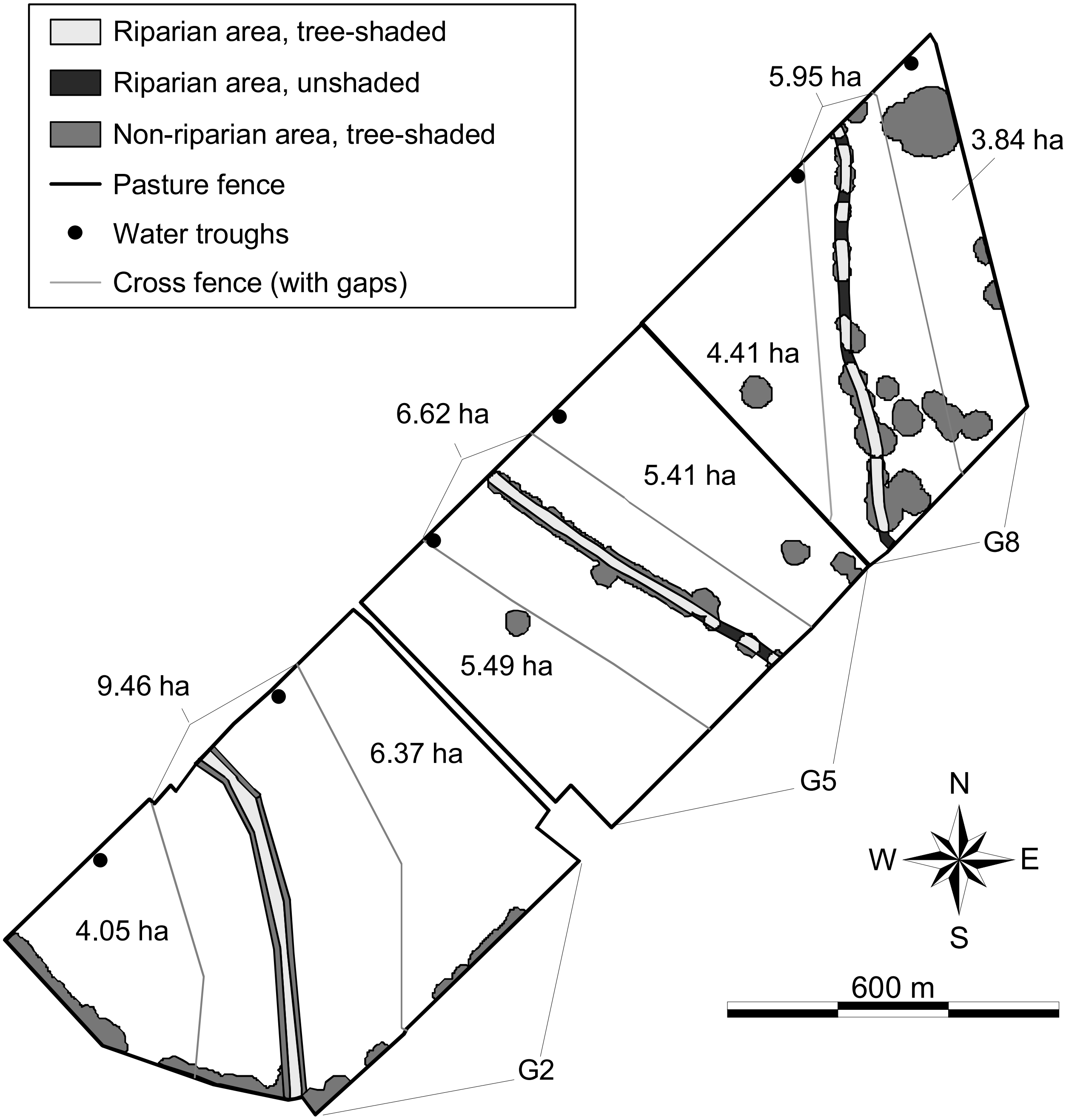

Fig 2.1. Map of three pastures showing tree-shaded areas, riparian areas, and fences. Riparian areas are defined as 12-m buffers centered on the stream. Tree-shade is defined as the crown diameter plus a 6-m buffer extending from the outer edge of the crown

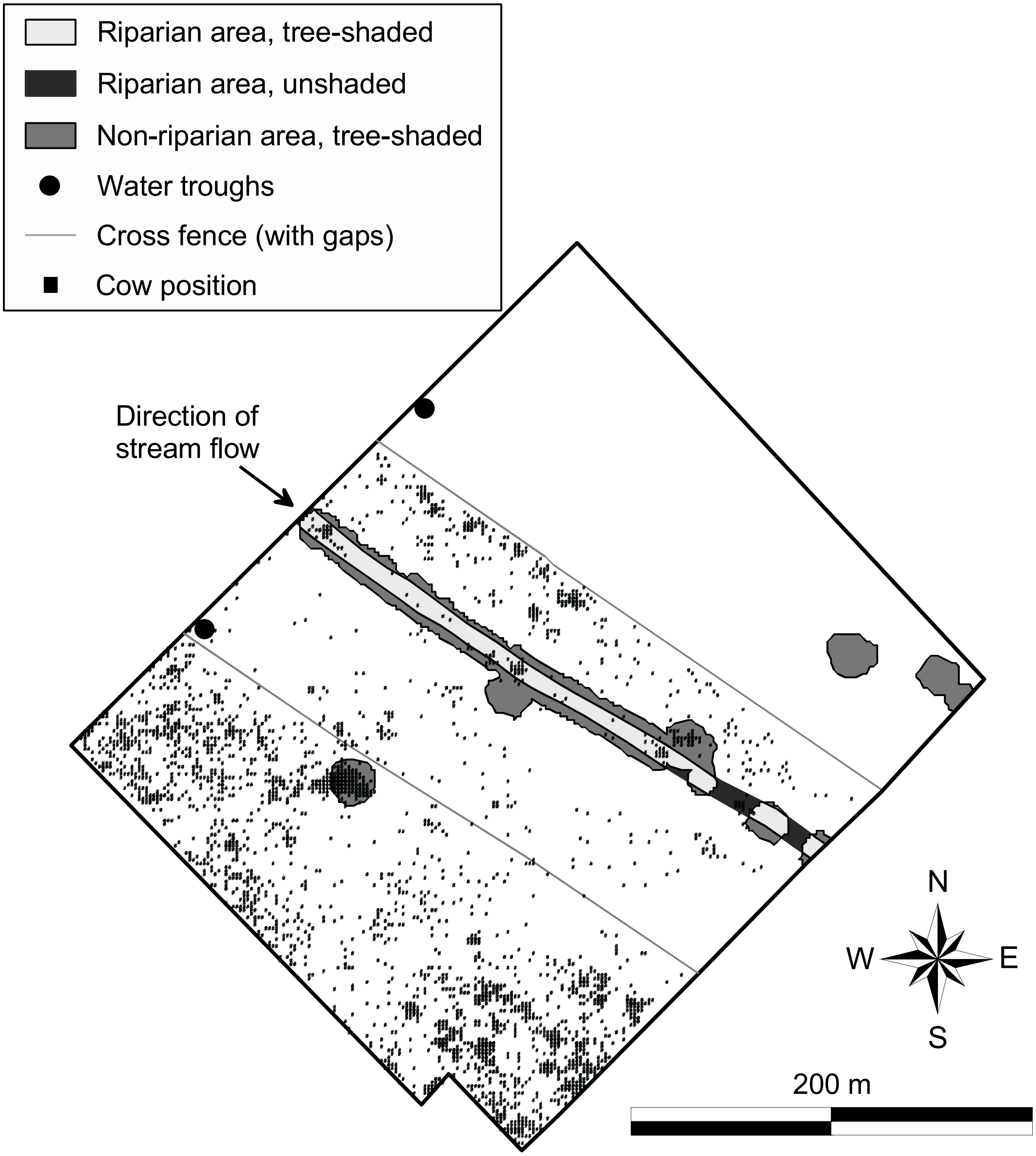

Fig 2.2. Map of pasture G5 showing tree-shaded areas, riparian areas, fences, watering troughs, and location of cow #413703 every 5-min between the dates 17 May and 3 June, 2003. A total of 4,847 differentially-corrected GPS data points were taken. Points that overlap are represented by one point. Riparian areas are defined as 12-m buffers centered on the stream. Tree-shade is defined as the crown diameter plus a 6-m buffer extending from the outer edge of the crown.

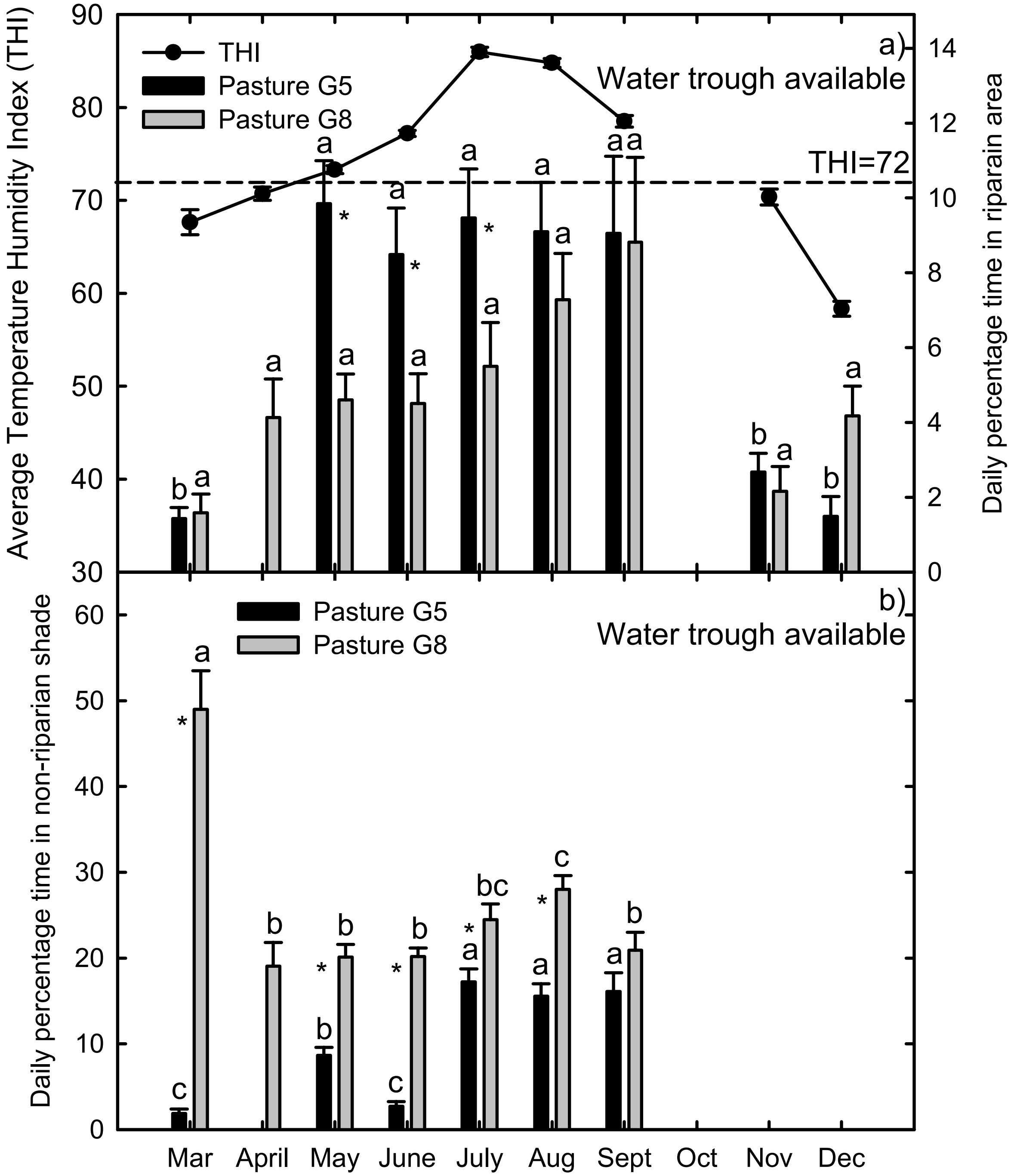

Fig 2.3. a) Average percentage of daily time in riparian zone and average Temperature Humidity Index (THI) at different times of the year and b) Average percentage of daily time in non-riparian shade. (Within each pasture, bars with a different letter are significantly different according to Fisher's LSD at p=0.05. Bars with stars are significantly different between pastures according to Fisher's LSD at p= 0.05). (error bars are standard errors).

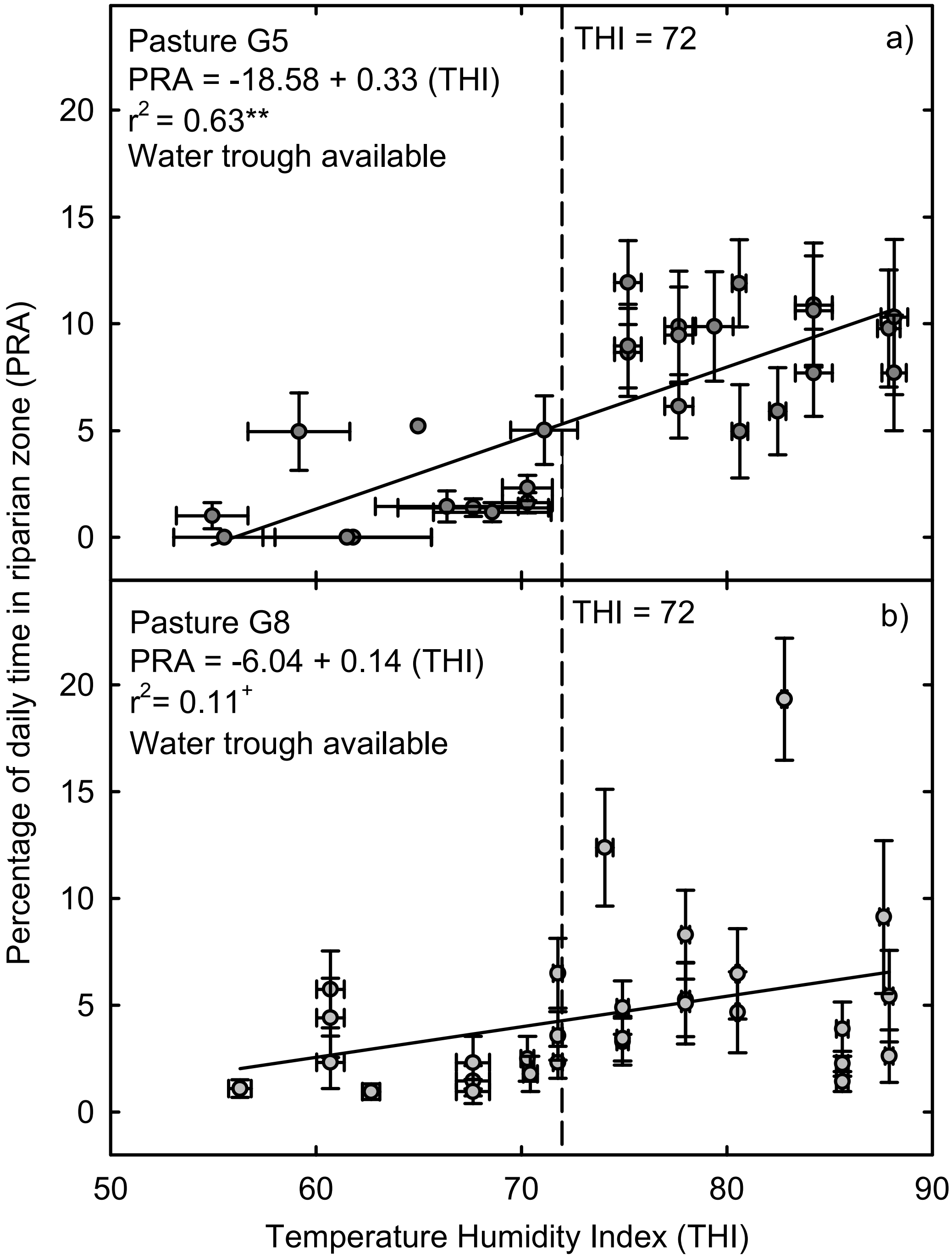

Fig 2.4. Percentage of daily time cattle spent in the riparian area as a function of Temperature Humidity Index (THI) for Pasture G5 (a) and Pasture G8 (b) (bars are standard errors; + and ** indicate significance at the 0.1 and 0.01 levels, respectively).

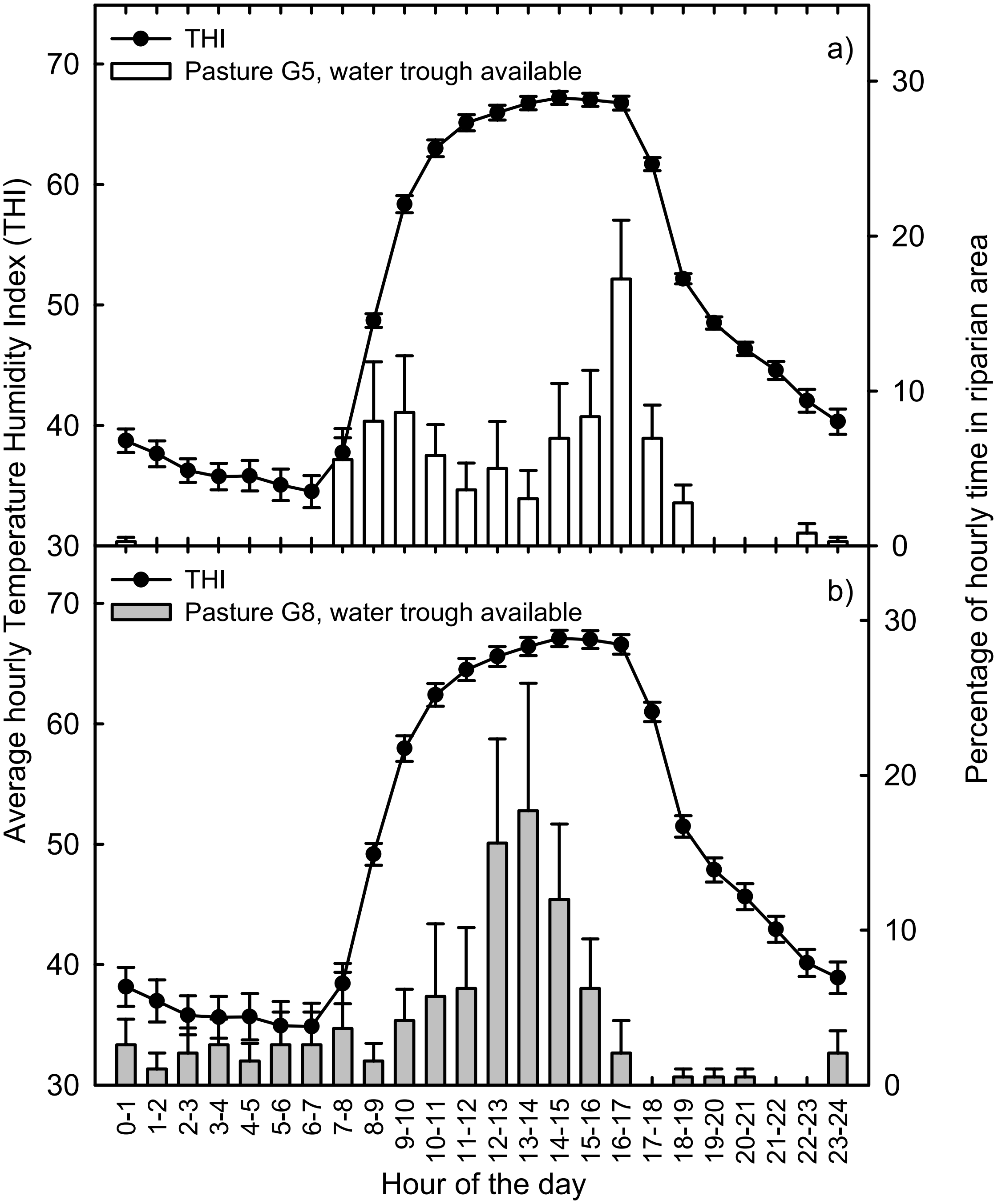

Fig 2.5. Average hourly THI and average percentage of hourly time cattle spent in the riparian areas of pastures G5 (a) and G8 (b) between 8 November and 22 November, 2001. The number of cows monitored were 3 in G5, and 2 in G8. (bars are standard errors)

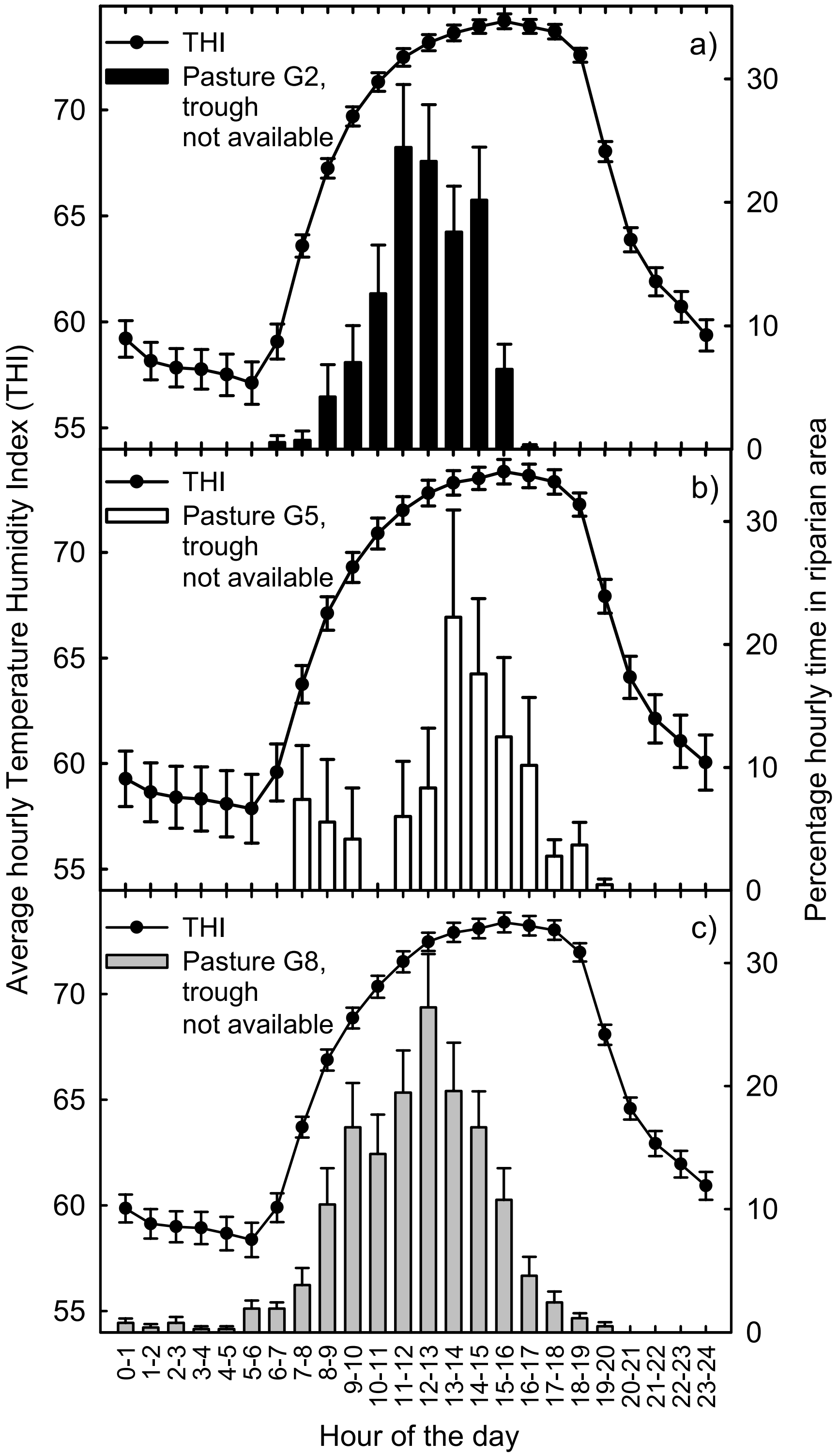

Fig 2.6. Average hourly THI and average percentage of hourly time cattle spent in the riparian areas of pastures G2 (a), G5 (b), and G8(c) between 17 May and 3 June, 2003. The number of cows monitored were 3 in G2, 2 in G5, and 4 in G8. (error bars are standard errors)

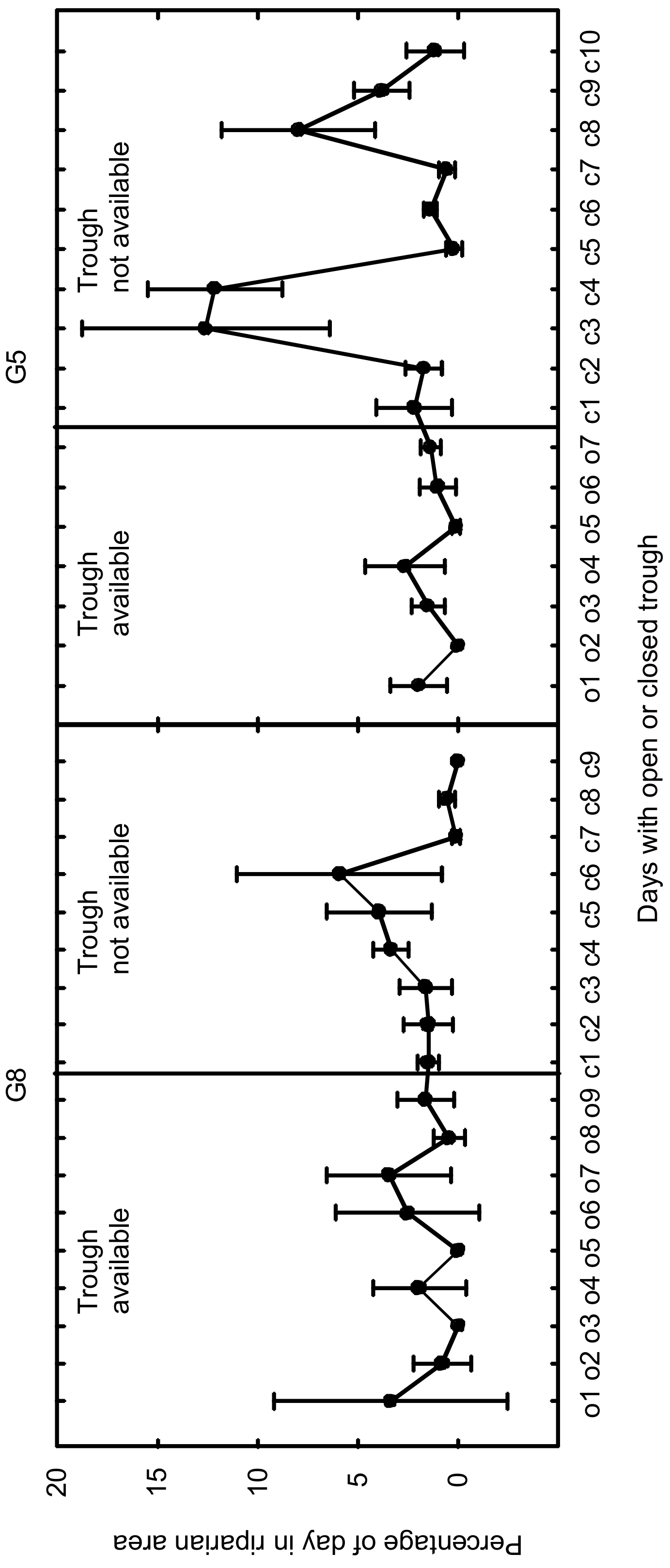

Fig 2.7. Percentage of daily time spent in the riparian area of pastures G8 and G5 as a function of trough condition starting 6 March, 2002.

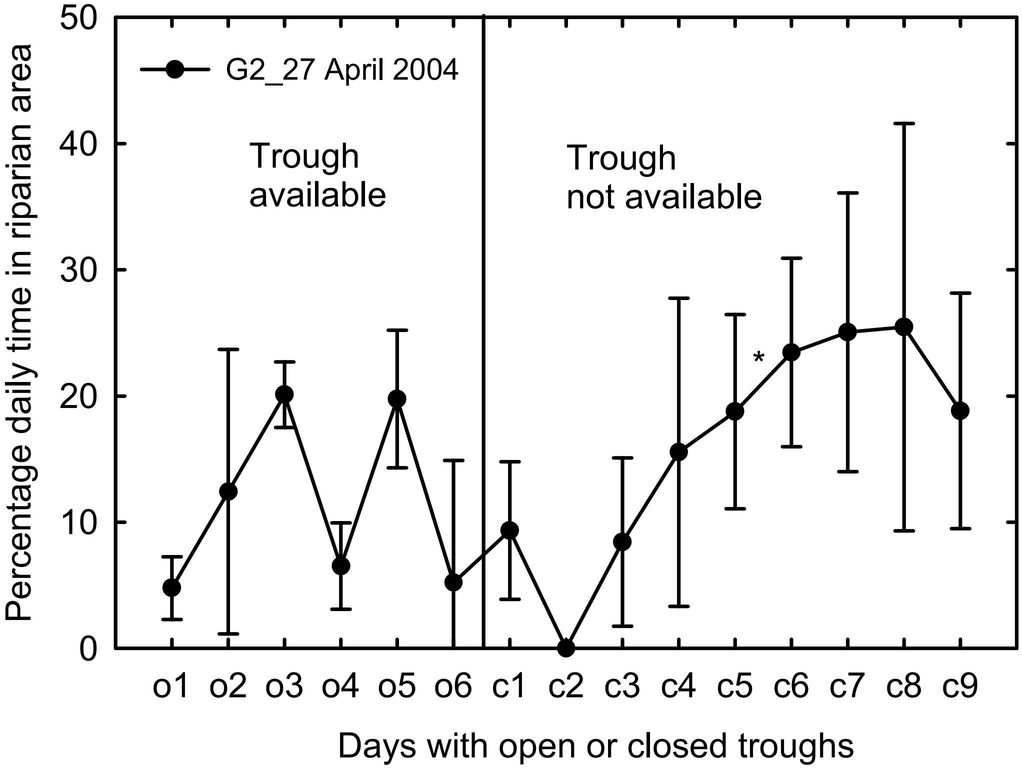

Fig 2.8. Average percentage of daily time spent in the riparian area of pasture G as a function of trough condition. (* Cattle broke the electric fence around the water troughs and gained access; the fence was repaired on day c7.)

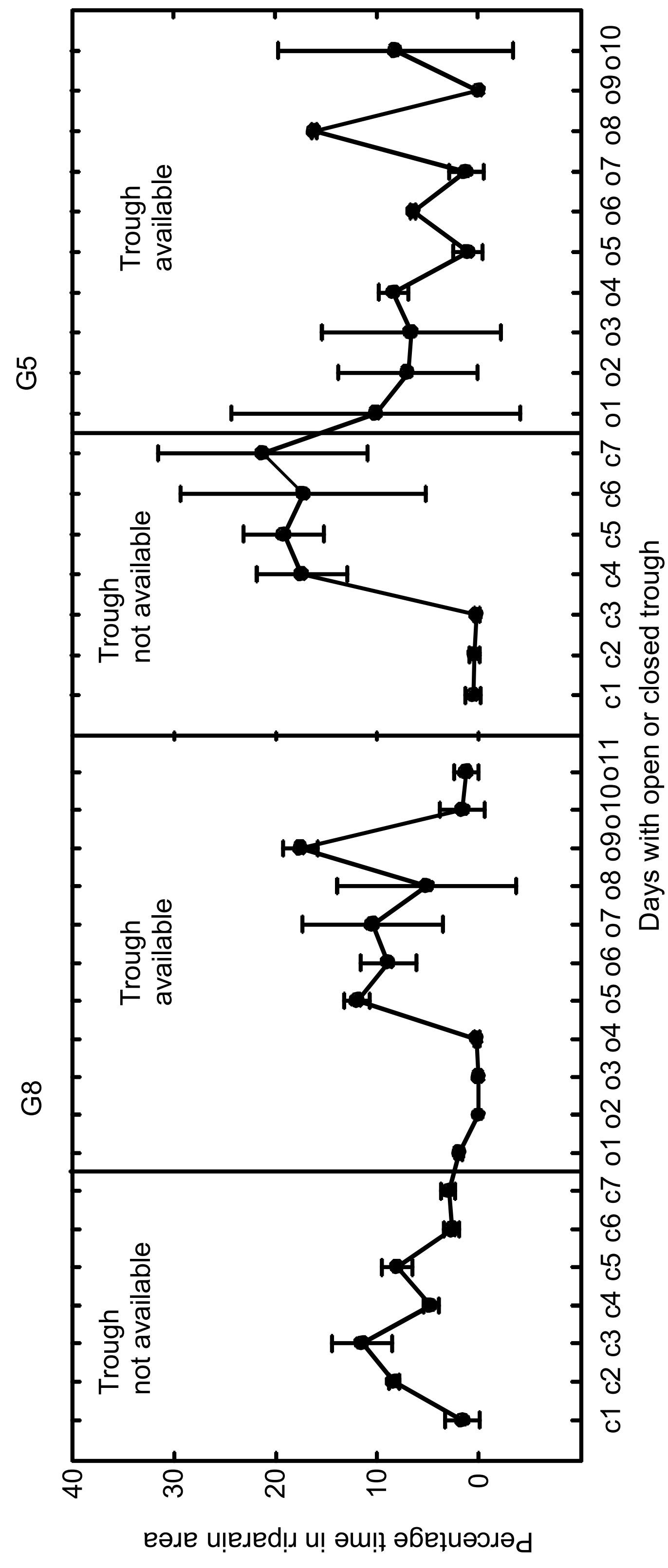

Fig 2.9 Percentage of daily time spent in the riparian area of pastures G8 and G5 as a function of trough condition starting 19 July, 2003.

CHAPTER 2

SEDIMENT, PHOSPHORUS, AND E. COLI LOADS IN STREAMS DRAINING TWO CATTLE-GRAZED PASTURES IN THE GEORGIA PIEDMONT, USA[1]

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[1] H.L. Byers, M.L. Cabrera, M.K. Matthews, D.H. Franklin J.G. Andrae, D.E. Radcliffe, M.A. McCann, H.A. Kuykendall, C.S. Hoveland, J.A. Rema, and V.H. Calvert II. To be submitted to *Journal of Environmental Quality*

Abstract

Contamination of unfenced streams in grazed pastures may be affected by the availability of shade and alternative water sources. The objectives of this study were to evaluate the effects of cattle on the water quality of two streams draining tall fescue/ bermudagrass pastures with different shade distributions, and to quantify the effects of alternative water sources on stream water quality. Loads of DRP, TP, and TSS, were measured during storm events and every 14 d during base flow in two unfenced streams in the Piedmont region of Georgia. Our results showed that grazing cattle in pastures with unfenced streams contributed significant loads of DRP, TP, TSS, and E. coli to surface waters ($p<0.01$). The loads contributed from the pastures appeared to be a function of shade distribution and water trough availability. Although storm flow was similar in both streams, loads of DRP, TP, and TSS were larger ($p< 0.08$) in the pasture with the smaller amount of non-riparian shade. The opposite trend was noted with respect to base flow in that the loads of TSS, and E. coli were larger in the pasture with the larger amount of non-riparian shade. This indicates that the amount of manure deposited near the stream was greater in the pasture with the smallest amount of non-riparian shade, and that the amount of manure deposited directly into the stream was greatest in the pasture with the largest amount of non-riparian shade. We believe the latter effect was caused by the fact that the stream in the pasture with the larger amount of non-riparian shade had pools where cattle like to linger. The stream in the other pasture did not have these pools. Water trough availability did not significantly alter the contaminant loads from the pasture with the smallest amount of non-riparian shade; however when the water trough was available in the other pasture, there were decreases ($p< 0.15$) in TP and TSS. When the water trough was available, there were significant ($p< 0.01$) decreases in the base flow loads of TP, TSS, and E. coli in the stream draining the pasture with the smaller amount of non-riparian shade, and decreases ($p<0.08$) in TSS and E. coli in the other pasture. Contaminant load reductions are in agreement with observed reduction in the time spent by cattle in the riparian area when water troughs were available,

which indicates that possible BMPs to reduce P, sediment, and E. coli contamination from beef-cattle-grazed pastures would be to build or encourage shade development away from the stream and to provide cattle with an alternative water supply away from the stream.

Introduction

Cattle grazing pastures with unfenced streams may lead to stream contamination with P, sediment, and pathogenic bacteria (Sauer et al., 1999, Line et al., 2000). Phosphorus is the limiting factor for many aquatic plants growing in fresh water. As a result, an increase in its availability may lead to eutrophication, which kills fish and other aquatic life (Correll, 1998). Sedimentation in surface waters can interfere with proper gill function in aquatic animals as well as embed pebbles in the streambed, which eliminates hiding and spawning places of aquatic flora. Pathogenic intestinal organisms from feces that are deposited in surface water can lead to health problems and possible death in humans as well as other animals drinking from contaminated waterways.

Phosphorus delivery to surface waters can occur via surface runoff, leaching, and eroded sediments. Runoff is the main delivery method of bioavailable P to surface waters (Sims et al., 1998). In addition, P can contaminate streams in grazed pastures through direct defecation by animals into the stream. Edwards et al. (2000) determined the concentration of P in fresh manure of beef cattle on a tall fescue diet to be 5,840 mg P kg^{-1}. Because a cow weighing 567 kg generates approximately 29 kg of manure per day, this translates into 0.37 kg of P cow^{-1} d^{-1}. Of this total amount of P, about 33% is orthophosphate (ASAE, 2002), which is directly available to plants and algae. Thus, cattle grazing pastures may result in heavy loading rates of P to streams. Line et al. (2000) determined that an unfenced stream flowing through a 14.9-ha pasture grazed by 60 dairy cows had a mean weekly TP load of 50 kg.

Direct deposition of P into streams may be particularly important in endophyte-infected tall fescue pastures, where animals have been reported to seek shade and water to alleviate the effect of fescue toxicosis. Ergot alkaloids produced by the endophyte in tall fescue have been shown to induce vascular constriction and therefore cause hyperthermia in cattle (Hoveland, 2003). As a result, cattle commonly seek shade or stand in bodies of water to aid in heat dissipation, especially during fescue seed production, which occurs during the late spring in Georgia. Consequently, the amount and location of shade in tall fescue pastures may play significant roles in determining the amount of P contamination in streams, but information is lacking on this subject.

By far in terms of volume, suspended sediment is the largest contaminant in surface waters (Cooper, 1993). Sediment from the stream channel is caused by sloughing of stream bank material which occurs naturally as the stream migrates, or by stream bed degradation and resuspension of sediment into the water column, but can be worsened by livestock (Myers and Swanson, 1996 and Clary, 1999). In addition when sediment with a large amount of sorbed P, reaches a reservoir chemical and biological conditions may make the P become available, leading to eutrophication.

Other stream contaminants in grazed pastures are pathogens present in animal manure. The most common fecal indicator bacteria discussed in the literature are Total Coliforms, Fecal Anerobes, Fecal Coliforms, and Fecal Enterococci. Edwards et al. (1997) collected runoff from pastures for three years and analyzed it for fecal coliform and fecal streptococcus bacteria. Runoff concentrations exceeded the primary contact standard 87% of the time and exceeded the secondary contact standard in 70% of the runoff events. Fecal Coliform and Fecal Streptococci contamination levels were significantly affected by seasonal variations with the highest concentrations of these bacterial contaminants being observed in warmer months, which could be due to regrowth during warmer months (Skinner et al., 1974, Jawson et al., 1982, and Tiedemann et al., 1988). The EPA recommended the use of *E. coli* as the preferred fecal indicator bacteria in 1986, as *E. coli* is a much more effective predictor of gastrointestinal illness than fecal coliforms, thus E. coli was the indicator bacteria measured in this study.

Fencing entire reaches of stream riparian areas has been proposed as a way to reduce P, sediment, and pathogen loads into streams. The high cost of fencing, however, prevents many livestock producers from fencing cattle out of streams (Line et al., 2000). An alternative to fencing may be installing water troughs away from the stream. The presence of an alternative-watering source for cattle reduced by 51% the amount of time cattle spent in the stream (Sheffield et al., 1997). Because cattle were not spending as much time in the stream, the flow-weighted concentration of TSS decreased from 132 to 14 mg L^{-1}, a 89% reduction; and TP decreased from 0.203 to 0.072 mg L^{-1}, a 65% reduction. In contrast, Line et al. (2000) concluded that water troughs alone did not significantly decrease the mean weekly discharge of TSS from cattle-grazed pastures. Clearly, additional work is needed to evaluate the effect of water troughs on stream water quality. Another factor that needs to be evaluated is the effect of shade distribution on stream water quality.

The objectives of this study were to quantify the effects of cattle on the water quality of two streams flowing through tall fescue pastures with different shade distribution, and to evaluate the effects of alternative watering sources on stream water quality.

Materials and Methods

Site description

The streams used in this study flowed through two pastures located at the Central Research and Education Center of the University of Georgia (Eatonton, GA; Latitude 33o24' N, Longitude 83o29' W, elevation 150 m). ISCO model 6700 portable samplers (ISCO, Lincoln, NE) were installed where the stream entered and exited each pasture (Fig 3.1). For the purpose of this paper, the pasture between water quality sampling stations G5 and G6 will be referred to as pasture G5G6, and the pasture between water quality sampling stations G8 and G9 will be referred to as pasture G8G9. The pasture area in G5G6 was 3.32 ha greater than that of G8G9, but the watershed areas were approximately the same (17.9 ha in G5G6 and 18.0 ha in G8G9). The streams in both pastures had been unfenced for over 10 yr and had been dredged in 1994 to improve pasture drainage

The two predominant forages in the pastures were endophyte-infected (*Neotyphodium coenophialum* Morgan-Jones and Gams) tall fescue (*Festuca arundinacea* Schreb.) and bermudagrass (*Cynodon dactylon* L.). The soils have been classified as Iredell sandy loam (Fine, montmorillonitic, thermic, Typic Hapudalf); Mecklenburg sandy loam and sandy clay loam (Fine, mixed thermic Ultic Hapludalf); and Chewacla silty clay (Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts) (Perkins et al., 1987).

To delineate the extent of the tree shade in each pasture, the crown diameter of each tree was surveyed after leaf-out with a submeter Trimble Model TSC1 GPS unit (Trimble, Sunnyvale, CA), and a 6-m buffer around the edge of the crown was created in ArcView GIS 3.2 using the Spatial Analyst (Environmental Systems Research Institute, Inc., Redlands, CA) and the Xtoolsmh extensions (Oregon Department of Forestry, Salem, OR). The submeter Trimble Model TSC1 GPS was also used to delineate pasture, stream, and cross fences as well as determine the position of the water troughs in the two pastures. From this survey it was determined that the pastures varied not only in the amount, but the distribution of tree-shade (Table 3.1). In both pastures, the majority of the shade available to cattle was in non-riparian areas, though the amounts of shade varied greatly. Pasture G8G9 had over twice the amount of total shade of pasture G5G6 and over three times the amount of non-riparian shade.

The pastures were stocked with 20 cow-calf (Angus and Angus-Hereford cross) pairs. Single strand, electric cross fences were installed before the project began, and were used to rotationally graze cattle on either side of the riparian area; however, cattle were allowed access to the entire riparian area throughout the duration of the study.

Two water troughs with water meters were installed in each pasture before the project began; and water meter readings were taken periodically during the study. The average distance from the water troughs to the stream was 91 m in G5G6 and 81 m in G8G9 (Fig. 3.1).

Monitoring of water quality during storm events took place both with water troughs available and with water troughs not available (Fig. 3.2). When water troughs were not available, an electric fence around the troughs prevented cattle access. At the onset of the project, the intention was to close the water troughs on 15 Mar., 2002 and keep the trough closed for one year; however, due to a lack of rainfall, the discharge of the streams dwindled to the point cattle could no longer drink sufficient amounts of water from the stream, thus the troughs were opened on 3 June, 2002. The troughs remained opened until 23 Dec., 2002, when sufficient flow in the streams allowed the troughs to be closed again until July 2003.

To remain conservative in the analysis, the data from the storm events and base flow sampling that took place with open troughs between 3 June and 23 Dec., 2002 were not used in this study, as it was feared that cattle may have been defecating at high rates near the riparian area areas during the previous time when the troughs were closed, thus loading the area heavily with contaminants. Therefore, when the troughs were opened after 3 June, 2002, any response to contamination would have been a factor of the loading rates near and in the riparian area while the troughs had been closed. For each station, the extreme outliers were removed so the comparison of each load between open and closed troughs would be carried out under a similar range of loads. The total number of storm events analyzed when water troughs were available were 14 in G5G6 and 22 in G8G9; and 24 storm events in G5G6 and 18 in G8G9 when water troughs were not available. The number of base flow samples taken while water troughs were available were 12 in G5G6 was and 17 in G8G9; and 21 base flow samples in G5G6 and 25 in G8G9 were taken when water troughs were not available.

Storm flow and base flow water quality — Sampling and equipment

In monitoring water quality during storm events, it is crucial to take multiple discrete water samples at several points through the event as the concentration in each sample is commonly a function of discharge and time since the storm event began. Therefore, to insure multiple discrete samples across the entire hydrograph of discharge, a DRUCK, PDCR 1230 pressure transducer (Druck Incorporated, New Fairfield, CT) was installed vertically-perpendicular to the stream through a PVC pipe attached to a t-post. The PVC pipe allowed the height of the water at the pressure transducer to be at equilibrium with the height of the water in the stream, but did not allow sediment and large debris to interfere with the pressure transducer's readings. The pressure transducer was connected to a Campbell Scientific CR510 datalogger (Campbell Scientific, Inc., Logan, Utah), which at predetermined stream heights would trigger the ISCO sampler to take a 500-mL water sample. The datalogger recorded the date, time, and stream height, every 15 min, as well as the water sample number associated with each sample taken. A 12-volt deep-cycle marine battery provided electricity and was recharged by a Solarex 60-W solar panel (Solarex, Frederick, MD). Following a storm event, water samples were retrieved and taken to the laboratory for analysis. To measure base flow concentrations, grab samples were taken every 14 d at the same points where storm flow samples were collected.

Storm flow and base flow water quality — Laboratory analysis

A 250-ml aliquot of each water sample was filtered trough a pre-weighed, acid-washed, 0.45-mm Supor-450 polyethersulfone filter (Pall Life Sciences, Ann Arbor, MI). The filter was then dried at 106°C for 24 h and reweighed to determine the total suspended solids (TSS); the filtrate was analyzed for Dissolved Reactive P (DRP) (Murphy and Riley, 1962). An unfiltered sample was analyzed for Total P following Kjeldahl digestion (USEPA, 1979). Base flow samples were further analyzed for Escherichia Coli (E. coli) using the Colilert (Idexx Laboratories Inc, Westbrook, ME) enzyme substrate method (Clesceri et al., 1998).

Storm flow water quality — Data processing

To determine the volume of discharge (m^3 s^{-1}) that moved past each water quality station during a storm event, a rating curve was developed to calculate flow at any given stream height. To construct the rating curve, the cross-sectional area of each stream was surveyed at 10-cm increments with a Model 300 Level (Berger Instruments, Braintree, MA), and the hydraulic radius was calculated. Stream velocity can be estimated using Manning's Equation; however, the roughness coefficient (Manning's N) is the most difficult parameter to estimate, as bank vegetation, rocks, and streambed structure all contribute to this parameter. Because Manning's Equation is very sensitive to this parameter, it became pertinent that Manning's N be calculated as accurately as possible at each water quality station; therefore, a 750-Area Velocity Module (ISCO, Lincoln, NE) was installed in the stream adjacent to the pressure transducer and attached to an extra ISCO sampler to measure velocity. Stream velocity data were used together with hydraulic radius and slope to estimate Manning's N for each station. Once Manning's N was determined, individual discharge rating curves for each water quality station were created using FlowMaster (Haestad Methods, Waterbury, CT).

Using the rating curves, the discharge for each station was calculated on a 15-min basis from 12 Mar, 2001 to 15 Aug, 2003. Each storm event was identified and the discharge for each storm flow water sample was integrated with respect to time in Mathcad 8.0 (Mathsoft Engineering & Education, Inc. Cambridge, MA) from the beginning of the event to the time the sample was taken. This provided the cumulative discharge (L storm^{-1}) at the time each sample was taken. The concentration (mg L^{-1}) of each contaminant was then integrated in Mathcad with respect to cumulative discharge to calculate the load (kg) of contaminant per storm flow event at each station. To calculate the load contributed by each pasture, the load at the upstream station was subtracted from the load at the downstream station (G5-G6 and G8-G9). Flow-weighted concentrations for stream flow generated in each pasture were calculated by dividing an event load of contaminant by the event volume of discharge.

Base flow water quality — Data processing

During base flow, the flow rate should not vary significantly during the day; therefore the instantaneous flow rate at the time each grab sample was taken was multiplied by the concentration of the corresponding grab sample to obtain a daily load. Instantaneous flow was obtained with the rating curves described above. Daily loads contributed by each pasture were calculated by subtracting the upstream load from the downstream load (G5-G6 and G8-G9).

Statistical analysis

Due to the nature of this study and the variability of the data, parametric statistical procedures were not applicable; therefore, the analysis was carried out with non-parametric methods. PROC UNIVARIATE (SAS Institute, Inc, 1998) was used on a per pasture basis to determine the median as well as the signed-rank statistic, which was used to determine if the median loads of DRP, TP, and TSS, as well as flow contributed by each pasture during storm events and base flow were significantly different from zero. PROC UNIVARIATE was also used to determine if one pasture contributed a greater load than the other.

The Kruskal-Wallis statistic under PROC NPAR1WAY (SAS Institute, Inc., 1998) was used to determine if the condition of the water troughs (open or closed) had an effect on the loads contributed from the pastures to their streams during storm events and base flow. The Kruskal-Wallis test is a nonparametric analysis of variance where the ranks of the data are analyzed rather than the data itself. The null hypothesis of the Kruskal-Wallis statistic is that both populations have the same continuous distribution. Therefore, this test will determine if the distribution of the ranks is different between two populations. To further evaluate the effect of water troughs on the contribution of contaminants from pastures to streams, PROC REG (SAS Institute, Inc, 1998) was used to construct a linear regression of the loads between the water quality stations upstream and downstream of each pasture during periods with open and closed troughs. PROC GLM in SAS was then used to test differences in intercept and slopes between regression equations.

Results and Discussion

Figure 3.3 shows a typical response of the stream in G5G6 to a storm event. Differences in flow between upstream and downstream stations were large, indicating a large flow contribution from pasture G5G6. Also, large TP concentrations were observed during storm events in association with large flow rates. Therefore, large loads were usually associated with large runoff events. Similar behavior was observed in G8G9.

Effect of shade distribution on water quality — Storm flow

Median loads and median flow-weighted concentrations in both streams clearly show that the pastures were contributing significantly ($p<0.01$) to the nutrient and sediment content as well as to the discharge of the streams flowing through them (Table 3.2 and Fig. 3.4). During the monitoring period, 29 kg of DRP, 242 kg of TP, and 237 Mg of TSS were lost in 240,000 m^3 of discharge from pasture G5G6. Pasture G8G9 contributed a total of 15 kg of DRP, 69 kg of TP, and 51 Mg TSS in 200,000 m^3 of flow during the same period. From these totals, it is clear that over the monitoring period pasture G5G6 contributed more nutrients and suspended solids to surface waters than G8G9. If the median TSS load per storm event is divided by the pasture area, the median rate of TSS loss per storm event was 121 kg ha^{-1} in G5G6 and 22 kg ha^{-1} in G8G9. Therefore, pasture G5G6 lost suspended solids at five times the rate of G8G9.

The median differences between G5G6 and G8G9 in loads of DRP, TP, and TSS as well as the median differences in flow-weighted concentration of DRP and TSS were significantly ($p<0.05$) different from zero (Table 3.3). The median difference in the flow weighted concentration of TSS was significantly different at $p=0.08$. These results show, as stated before, that G5G6 contributed more nutrient enrichment and sediment addition to surface water than G8G9. Because flow was similar between streams, the higher nutrient and sediment inputs in G5G6 must be due solely to environmental inputs, specifically cattle behavior. In an analysis of separate data collected in this study (Byers et al., 2004) we found that in May, June, and July cattle spent 9.3% of the day in the riparian area of G5G6, as opposed to 4.9% in the riparian area of G8G9. Thus, cattle spent about 50% more time in the riparian area of G5G6 than in that of G8G9. We also found that in May, June, and July, cattle in G8G9 spent 21.5% of the day in non-riparian shade whereas cattle in G5G6 spent 9.5% in non-riparian shade. In G5G6 67% (4,310 m^2) of non-riparian shade was adjacent to or within 25-m of the riparian area, while in G8G9 only 28 % (5,189 m^2) of the non-riparian shade was within 25-m of the stream (Fig. 3.1). Thus, the larger loads of DRP, TP, and TSS in G5G6 than in G8G9 were probably caused by cattle spending more time in or within 25-m of the riparian area in G5G6. These results suggest that providing or encouraging shade away from the stream may be a good BMP to reduce P and TSS loads from grazed tall fescue pastures during storm flow.

These results may lead to the conclusion that one way to discourage cattle use of the riparian area is to remove trees from the riparian area. We are not, however, advocating this conclusion. Tree-shaded areas provide many crucial services in maintaining a healthy aquatic ecosystem (Bjorkland et al., 2001). In terms of habitat, these trees provide a cooler microclimate for aquatic organisms and their roots provide protected habitat. Trees in aquatic ecosystems also provide organic material to organisms on the lower links of the food chain. Finally, in terms of TSS, trees help control erosion and dissipate energy during storm events (Bjorkland et al., 2001).

Effect of shade distribution on water quality — Base flow

Both pastures contributed significantly ($p<0.01$) to the concentration of DRP, TP, TSS, and E.coli in surface waters during base flow (Table 3.4, Fig. 3.5, and Fig. 3.6). The median differences in daily loads of DRP, TSS, and E. coli between the two pastures (G5G6-G8G9) were significantly different from zero ($p=0.07$), indicating that the unfenced pastures were not contributing similar loads of contaminants to the stream (Table 3.5). The pasture with the greater amount of non-riparian shade (G8G9) contributed significantly ($p< 0.05$) larger loads of

E.coli and TSS to surface waters on a daily basis. In G8G9 cattle appeared to make short discrete visits to the stream, but did not linger in areas adjacent to the stream, and instead prefer to linger in non-riparian shaded areas away from the stream. This is most likely due to the presence of two large pools in this stream. The base flow results coupled with storm flow results suggest that the amount of manure deposited near the stream was greater in pasture G5G6 and the amount of manure deposited directly into the stream was greater in G8G9. Thus, because the larger loads were observed under storm flow, these results still support the recommendation of providing cattle with abundant non-riparian shade.

Effect of water trough on water quality — Storm flow

In G8G9, median loads of TP and TSS were larger when water troughs were not available ($p< 0.15$); and in G5G6, differences in loads appeared not to respond to water trough availability (Table 3.6 and Fig. 3.8).

Effect of water trough on water quality — Base flow

In the stream draining pasture G5G6, median daily loads of DRP (1.48 vs. 9.87 g day^{-1}), TP (62.2 vs. 144.1 kg day^{-1}), TSS (1.81 vs. 34.32 kg day^{-1}), and E.coli ($1.92x10^8$ vs. $3.73x10^9$ CFU day^{-1}) were significantly ($p< 0.01$) decreased when the water trough was available (Table 3.7, Figure 3.9, and Figure 3.10.a). The flow was smaller ($p <0.01$) during the time the trough was open (423.4 vs. 876.3), but since the magnitude of change in contaminant load was greater than the magnitude in change of flow, it can be concluded that the water troughs had a significant effect on reducing daily water quality in this stream. When the trough was not available, cattle were forced to the stream to drink. As they walk in and out of the stream, their hooves break down the stream bank and destroy stream-bank vegetation, thus when a storm event occurs, the stream bank is less stable and higher sediment levels are observed. The ability of the water trough to significantly decrease surface water contamination is supported by the accompanying behavior study (Byers et al., 2004) in that in the presence of a water trough, cattle in pasture G5G6 significantly decreased the amount of time spent in the riparian area, ergo it is expected contamination loads should decrease.

In pasture G8G9, providing cattle with a water trough decreased ($p = 0.08$) the daily loads of TSS (21.2 vs. 59.0 kg day^{-1}) and E. coli (1.15x10^{9} vs. 7.68x10^{9}) (Table 3.7, Figure 3.10.b, and Figure 3.11). Unlike pasture G5G6, the flow in G8G9 was not different ($p = 0.69$) when the water trough was closed (750.96 vs. 615.85 m^{3} day^{-1}); therefore, the decrease in contamination is a direct function of trough condition. The accompanying behavior study (Byers et al., 2004) indicated that in the presence of a water trough cattle tended to spend less time in the riparian area, though this was not a significant change.

In Virginia, Sheffield et al. (1997) demonstrated a 27-fold decrease in TSS (293 vs 11 kg cm rain-1) with the installation of a watering trough. Line et al. (2000) noted a decrease in the load of TSS (1,675 vs 1,031 kg week^{-1}) after installing a watering trough. In our case, we started with the water trough open, then closed the trough one year later; therefore, our methods were opposite of those of Sheffield et al. (1997) and Line et al. (2000), and although the results were similar, the magnitudes we observed were much smaller than those of Sheffield et al. We found that by closing the water trough in G5G6, the median TSS load increased 12-fold (2276 vs 181 kg storm^{-1}); the corresponding values for closing the water trough in G8G9 indicate a 6-fold increase in median TSS load (1235 vs 126 kg storm^{-1}). With respect to base flow, closing the water trough resulted in a 18-fold increase in TSS (1.81 vs. 34.32 kg day^{-1}) in G5G6 and a 3-fold increase (21.2 vs. 59.0 kg day^{-1}) in G8G9.

Sheffield et al. (1997) demonstrated a 41-fold decrease in TP load (3.25 vs 0.08 kg cm rain^{-1}) after giving cattle an alternative water source. Line et al. (2000) noted a slight increase in TP (3.9 vs 4.4 kg week^{-1}) after installing a watering trough. For storm flow, closing the water trough resulted in a 14-fold increase in median TP load (7.4 vs 0.50 kg storm^{-1}) in G5G6 and a 5-fold increase in median TP load (2.25 vs 0.47 kg storm^{-1}) in G8G9. For base flow, closing the water troughs resulted in a 2-fold increase (62.2 vs. 144.1 g day^{-1}) in G5G6, but resulted in a 2-fold decrease (167.7 vs. 96.1 g day^{-1}) in G8G9. Therefore, it is not possible to clearly draw a conclusion as to the benefit of a water trough on TP load reductions at this time.

Closing the water trough had the greatest effect on the median load of E.coli, which increased 19-fold ($1.92x10^8$ vs. $3.37x10^9$ cfu day^{-1}) in G5G6 ($p< 0.01$) and 7-fold ($1.15x10^9$ vs. $7.68x10^9$ cfu day^{-1}; $p = 0.08$) in G8G9 (Table 3.7, Fig. 3.10). Sheffield et al. noted a 51% reduction in Fecal Coliform load after the installation of a water trough (1997).

One factor that may have decreased the expected effect of water troughs on base flow and storm flow is that the average daily THI during March through July was significantly ($p< 0.01$) larger when the troughs were available. A larger THI would tend to force cattle to spend more time directly in the water. This could not be confirmed because of limited GPS resolution.

Summary and Conclusions

Our results clearly show that grazing cattle in pastures with unfenced streams contributed significant loads of DRP, TP, and TSS to surface waters during storm events and significant loads of DRP, TP, TSS, and E. coli during base flow. The loads contributed from the pastures appeared to be a function of shade distribution and water trough condition. In pastures with the majority of shade in close proximity to the stream, the effect of grazing cattle on stream loads during storm events was more detrimental than in pastures where most of shade was away from the stream. The increase of contaminant load appeared to be a direct response to the amount of time cattle spent in the riparian area. This response could be further observed during times when the water trough was closed. Cattle forced to the stream to drink in pastures with limited non-riparian shade tend to linger in the riparian areas longer than cattle with abundant non-riparian shade, thus increasing contaminant loads during storm events. This trend was reversed during base flow, as the pasture with the largest amount of shade away from the stream also had the highest load of contamination, indicating a constant flushing of the pasture by the stream, as opposed to flushing of contamination during storm events. The results of this study indicate that potential BMPs to reduce nutrient and sediment contamination from beef cattle-grazed pastures would be to build or encourage shade development away from the stream, and to provide cattle with an alternative watering source away from the stream.

Acknowledgements

We would like to thank the entire staff of the Central Research and Education Center for their help in this study. Specifically, we would like to acknowledge the late Tom Fitzgerald, Chad Westmoreland, Frank Newsome, Gerald Cathey, Timothy Hunnicutt, Johnnie Hash, and Eric Brazil for their assistance in maintaining a healthy grazing system and herd of cattle. We would like to recognize the valuable contributions of John Rema, Zach Alexander, Jennifer Cummings, and Shelby Finch in filtering, processing, and analyzing the samples. We are grateful to the National Resources Conservation Service for financial support of this project, and to Dr. Glenn Ware for his expertise and assistance in analyzing the data.

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Table 3.1. Tree-shaded area, riparian area, and total area of two pastures with unfenced streams

	Pasture	
	G5G6	G8G9
	m^2	
Non-riparian area, tree-shaded	6,425	18,523
Riparian area, tree-shaded	4,212	5,010
Total area, tree-shaded	10,637	23,533
Total riparian area	4,961	6,406
Total pasture area (ha)	17.52	14.20
	%	
Non-riparian area, tree-shaded (as % of total shade)	60	79
Riparian area, tree-shaded (as % of total shade)	40	22
Riparian area, tree-shaded (as % of riparian area)	85	78

Table 3.2. Median loads, and median flow-weighted concentrations of dissolved reactive P (DRP), total P (TP), and total suspended solids (TSS), and median flow per storm event in two unfenced-streams running through cattle grazed pastures during 2001-2003.

	Pasture	
Variable	G5G6	G8G9
	Median Load (kg $storm^{-1}$)	
DRP	0.075	0.102
TP	1.94	0.99
TSS	2121	311
	Median Concentration (mg L^{-1})	
DRP	0.050	0.036
TP	0.64	0.42
TSS	507	218
	Median Flow (m^3 $storm^{-1}$)	
	2175	2131

Note: All values are significantly different from zero at $p < 0.01$; n= 38 for G5G6 and n=40 for G8G9.

Table 3.3. Median differences (G5G6-G8G9) in load and flow weighted concentration of dissolved reactive P (DRP), total P (TP), and total suspended solids (TSS), and median differences in flow per storm event in two unfenced-streams running through cattle grazed pastures during 2001-2003.

Variable	G5G6-G8G9	
	Median Load (kg storm^{-1})	$p \geqq \lvert s \rvert$
DRP	0.042	0.024
TP	0.567	0.019
TSS	786	0.031
	Median Conc. (mg L^{-1})	$p \geqq \lvert s \rvert$
DRP	0.026	0.037
TP	0.227	0.047
TSS	58	0.076
	Median Flow (m^{3} storm^{-1})	$p \geqq \lvert s \rvert$
	-170	0.712

Note: Differences were evaluated by the signed-rank (s) test

Table 3.4. Median loads of dissolved reactive P (DRP), total P (TP), total suspended solids (TSS), E. coli, and base flow per day in two unfenced streams running through cattle grazed pastures during 2001-2003.

	Pasture	
Variable	G5G6	G8G9
DRP (g d^{-1})	2.91	2.77
TP (g d^{-1})	98.2	104.8
TSS (kg d^{-1})	16.6	37.4
E. coli (CFU d^{-1})	1.4×10^9	2.5×10^9
Flow (m^3 d^{-1})	641	622

Note: All values are significantly different from zero at $p < 0.01$. n= 33 for G5G6 and n=42 for G8G9.

Table 3.5. Median differences (G5G6-G8G9) in load, of dissolved reactive P (DRP), total P (TP), total suspended solids (TSS), E. coli, and median differences in flow per day in two unfenced-streams running through cattle grazed pastures during 2001-2003.

Variable	G5G6-G8G9	$p \geqq \lvert s \rvert$
DRP ($g\ d^{-1}$)	2.87	0.07
TP ($g\ d^{-1}$)	-3.3	0.84
TSS ($kg\ d^{-1}$)	-12.4	0.04
E. coli ($CFU\ d^{-1}$)	-2.5×10^{9}	< 0.01
Flow ($m^{3}\ d^{-1}$)	97.4	0.94

Note: Differences were evaluated by the signed-rank (s) test

Table 3.6. Median loads of DRP, TP, and TSS per storm event in pastures G5G6 and G8G9 with water troughs available and not

Pasture	Variable	Water Trough Condition Available	 Not Available	p>chi-square Kruskal-Wallis
		kg storm^{-1}		
G5G6	DRP	0.13	0.07	0.19
	TP	0.5	7.4	0.55
	TSS	181	2276	0.29
G8G9	DRP	0.03	0.12	0.59
	TP	0.47	2.25	0.15
	TSS	216	1235	0.13

Table 3.7. Median daily loads of DRP, TP, TSS, and E. coli during base flow in streams draining pastures G5G6 and G8G9 with water troughs available or not available

Pasture	Variable	Water Trough Condition Available	Water Trough Condition Not Available	p>chi-square Kruskal-Wallis
G5G6	DRP (g d^{-1})	1.48	9.87	< 0.01
	TP (g d^{-1})	62.2	144.1	< 0.01
	TSS (kg $d^{-1)}$	1.81	34.32	< 0.01
	E. coli (CFU d^{-1})	1.92×10^{8}	3.73×10^{9}	< 0.01
G8G9	DRP (g d^{-1})	0.86	3.38	0.23
	TP (g d^{-1})	176.7	96.1	0.49
	TSS (kg $d^{-1)}$	21.2	59.0	0.06
	E. coli (CFU d^{-1})	1.15×10^{9}	7.68×10^{9}	0.08

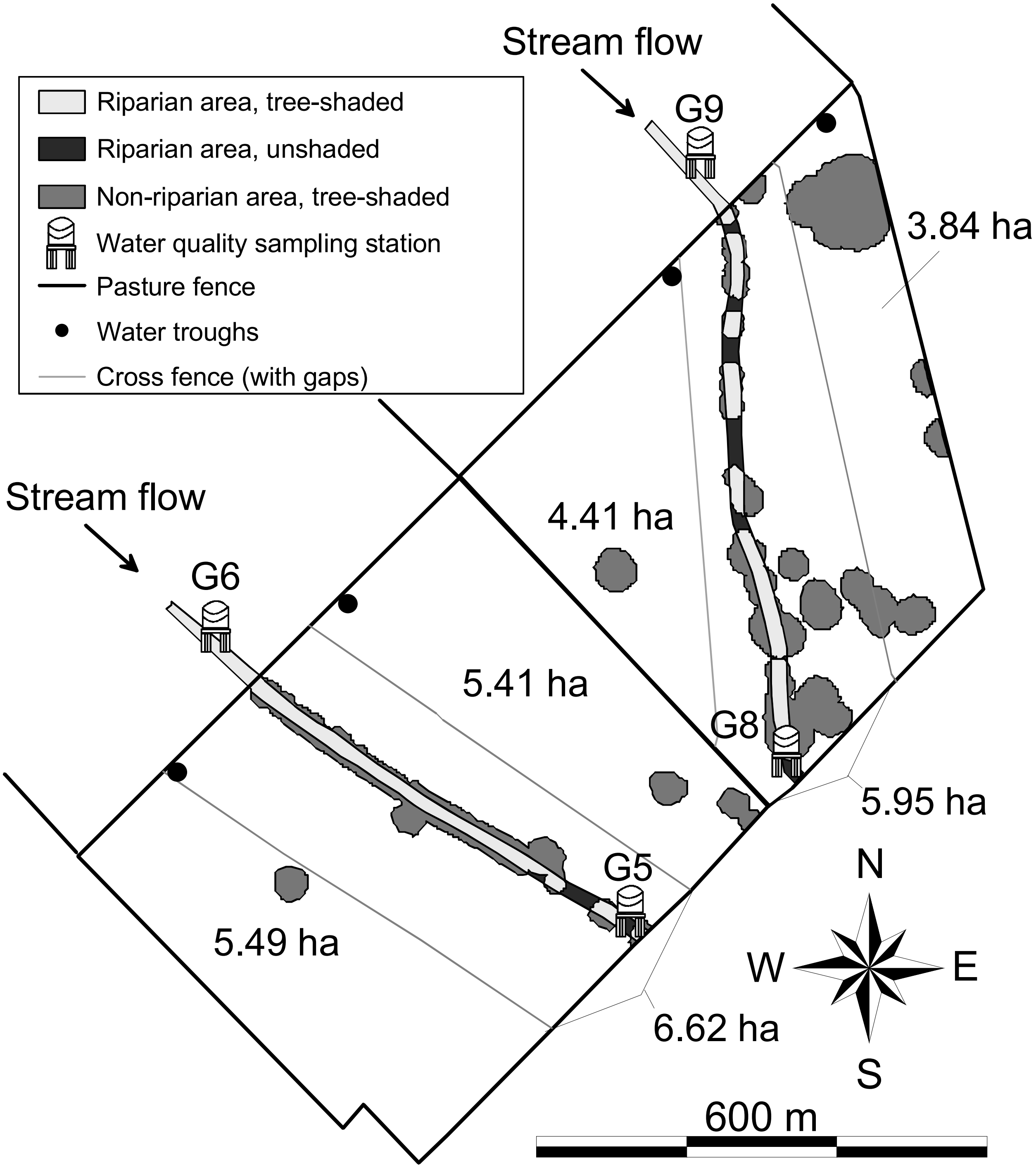


Fig 3.1. Map of pastures G5G6 and G8G9 showing tree-shaded areas, riparian areas, fences, watering troughs, and water quality sampling stations. Riparian areas are defined as 12-m buffers centered on the stream. Tree-shade is defined as the crown diameter plus a 6-m buffer extending from the outer edge of the crown.

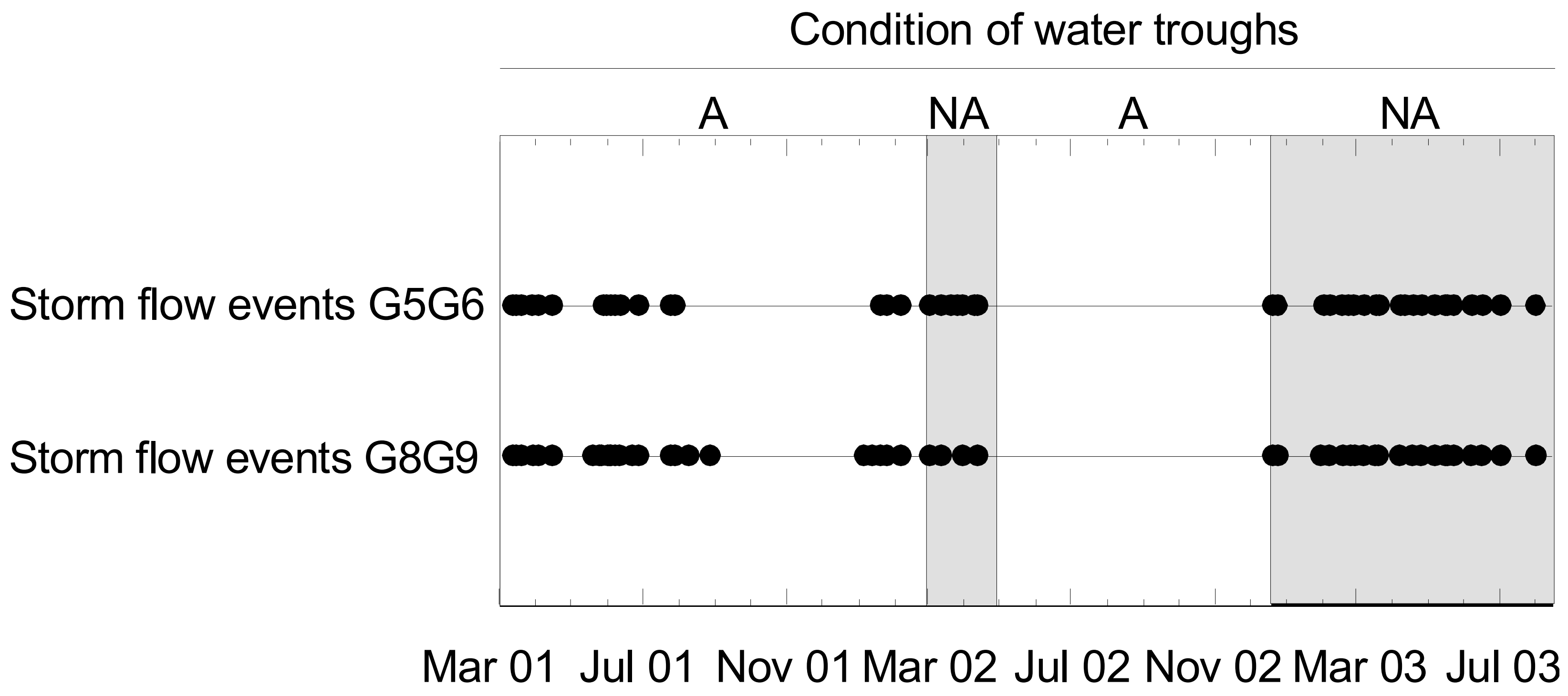


Fig 3.2. Storm events (indicated by circles) and condition of water troughs (a=available; na=not available) in pastures G5G6 and G8G9 from 1 Mar, 2001 to 15 Aug, 2003.

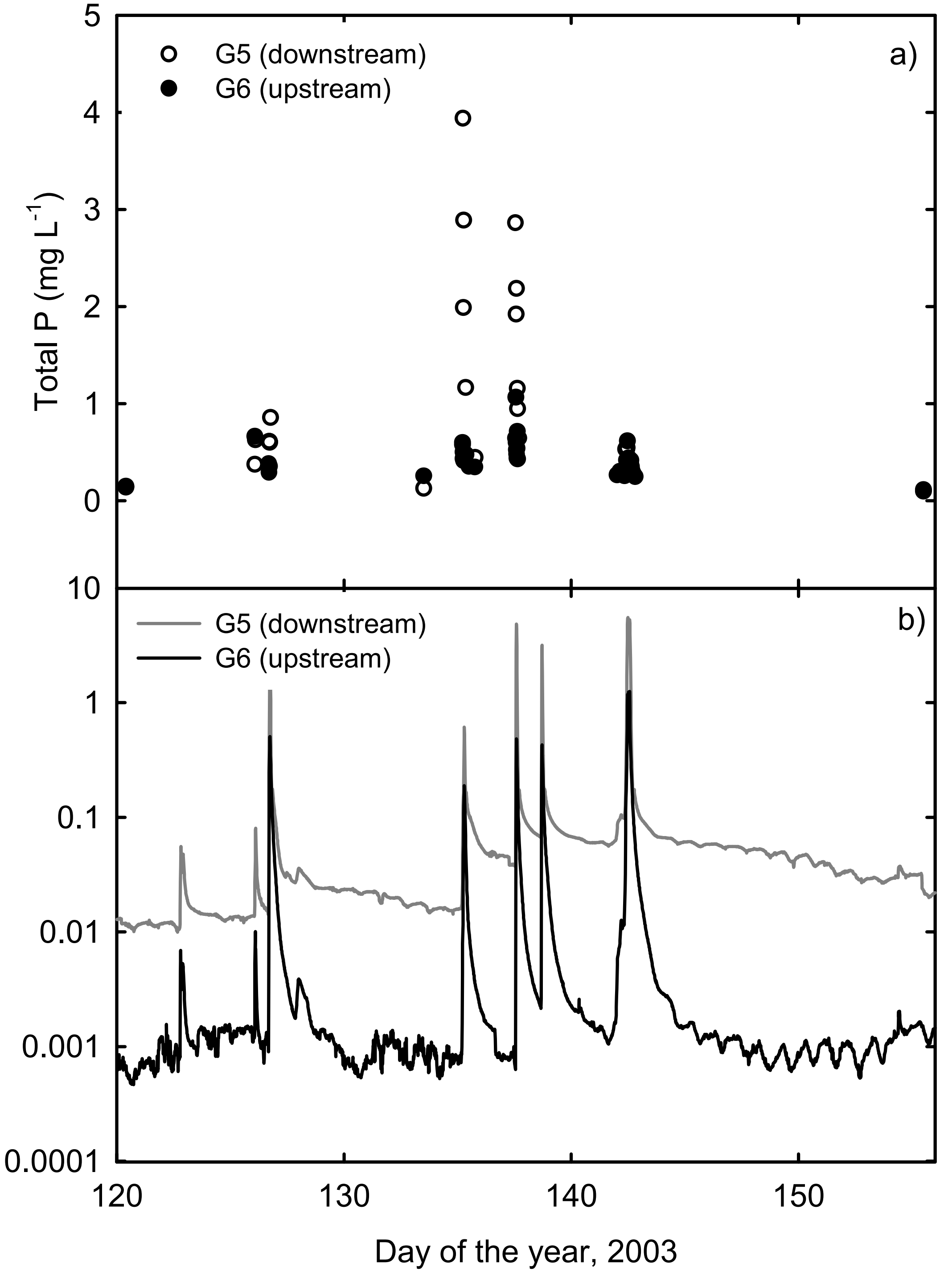


Fig 3.3. Total P concentration (a) and corresponding flow (b) at water quality stations G5 (downstream) and G6 (upstream) between 30 April and 5 June, 2003.

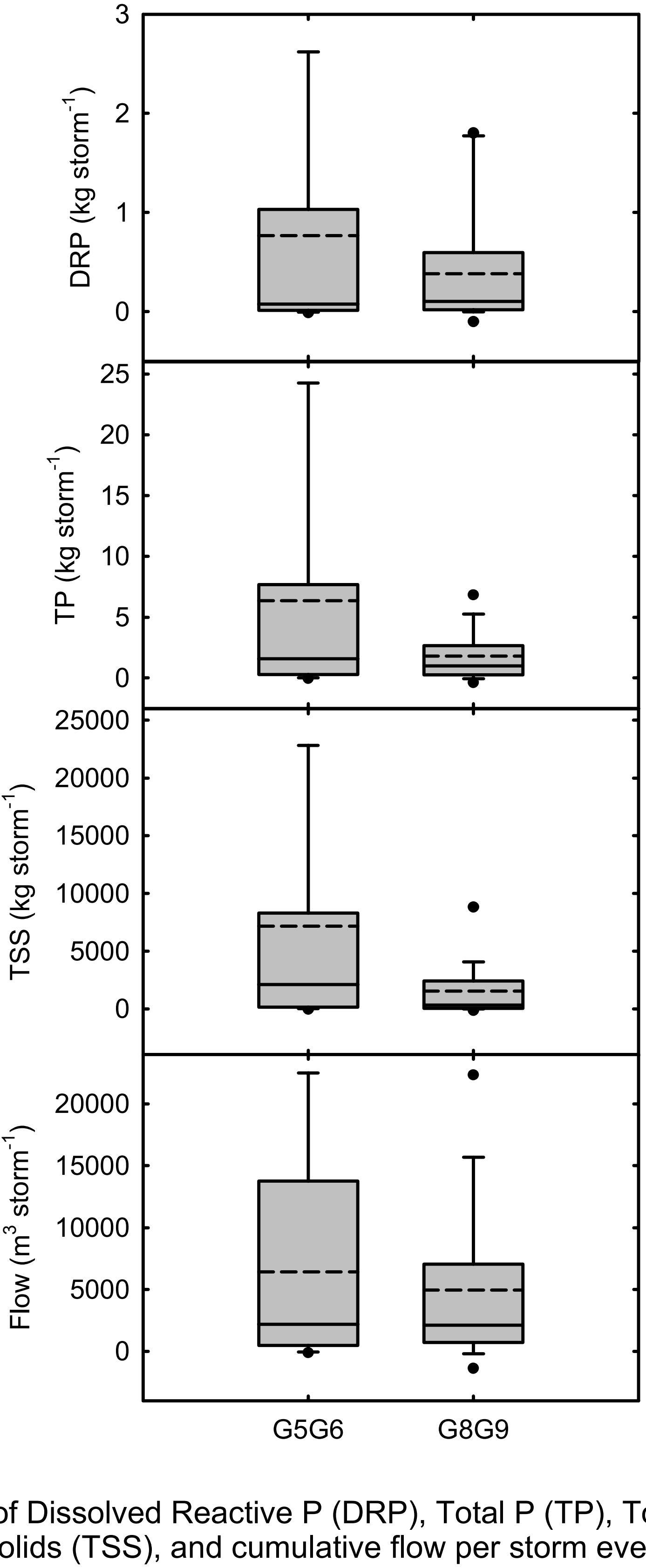


Fig 3.4. Loads of Dissolved Reactive P (DRP), Total P (TP), Total Suspended Solids (TSS), and cumulative flow per storm event in pastures G5G6 and G8G9. Interior solid lines are medians and dash lines are means.

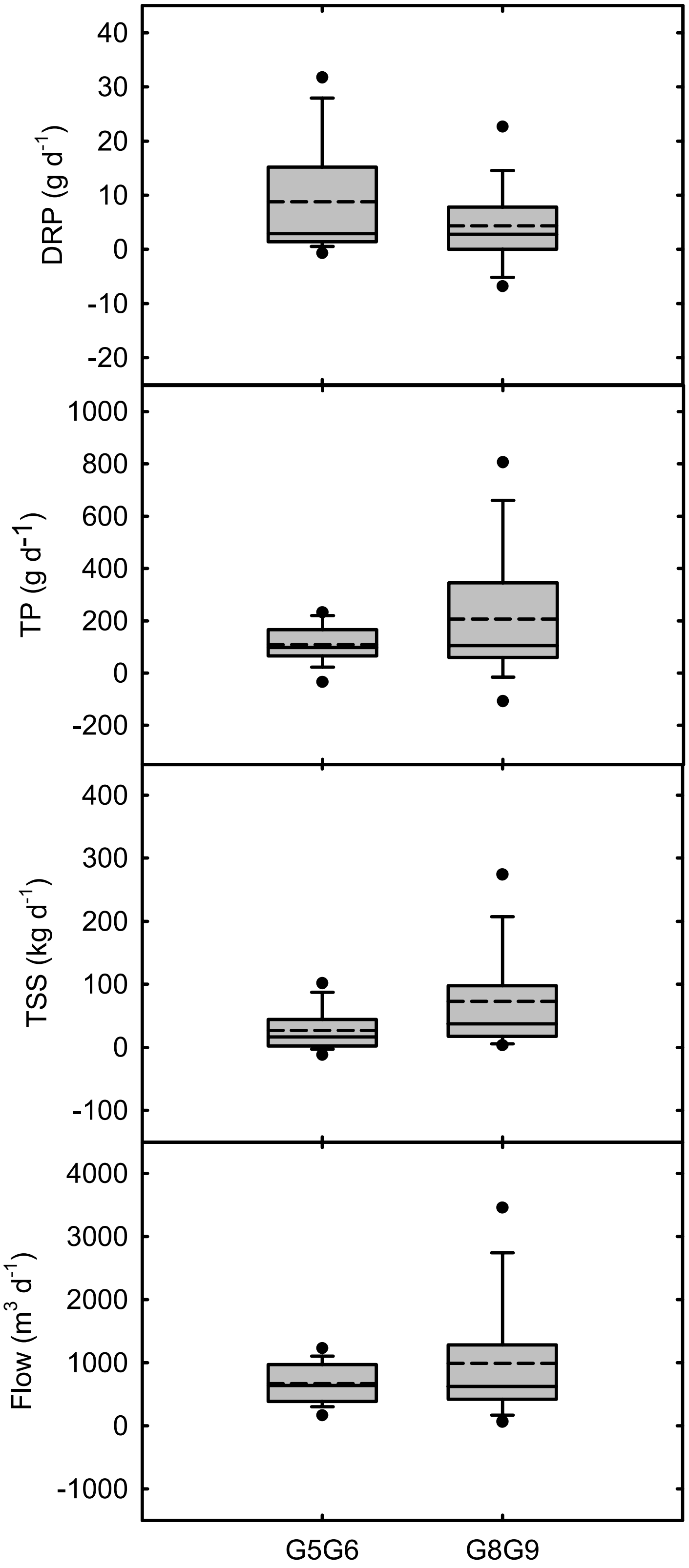


Figure 3.5. Daily loads of Dissolved Reactive P (DRP), Total P (TP), Total Suspended Solids (TSS), and daily base flow in streams draining pastures G5G6 and G8G9. Interior solid lines are medians and dash lines are means.

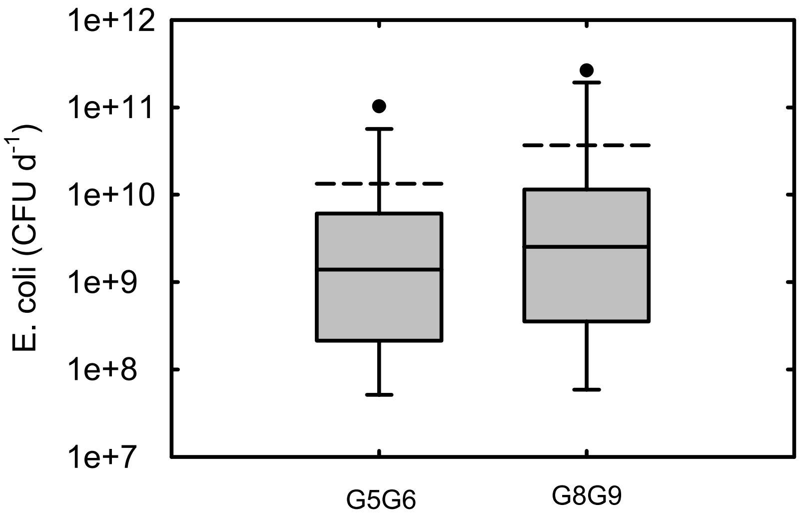
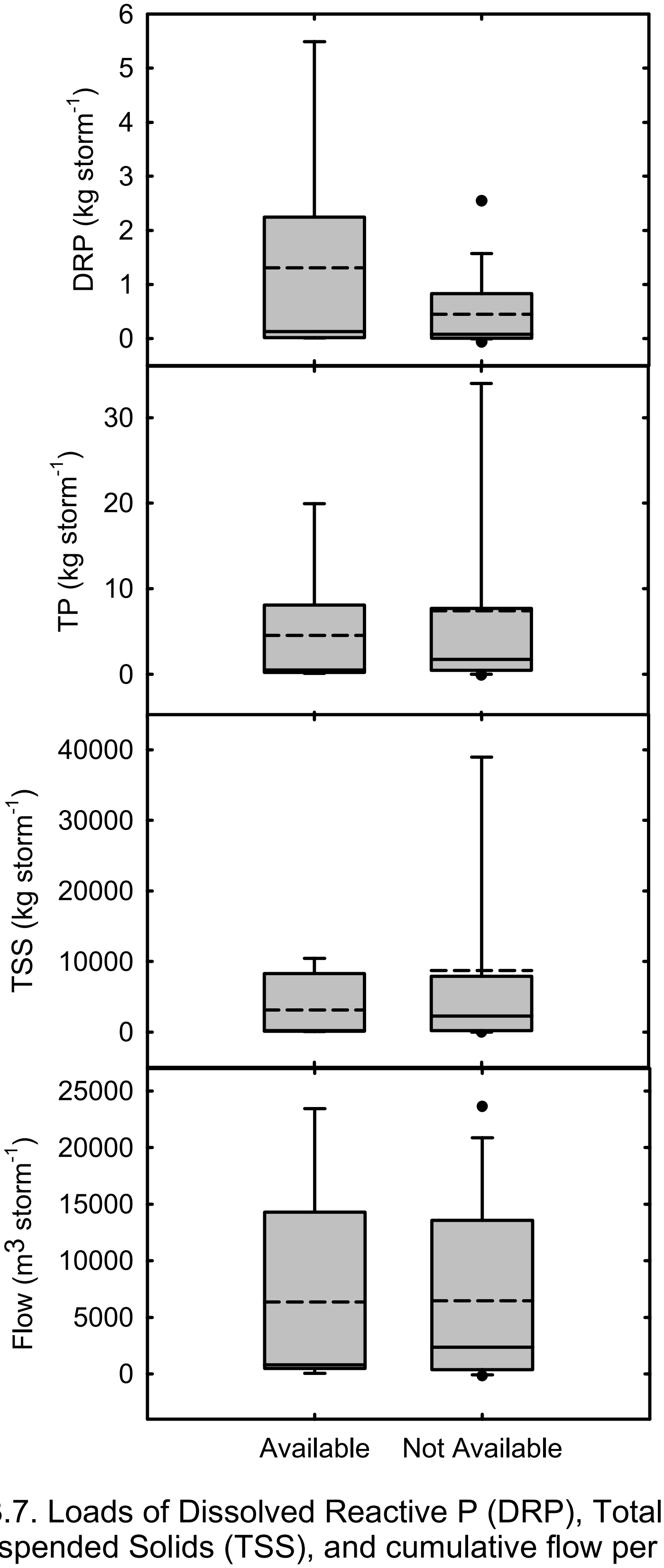
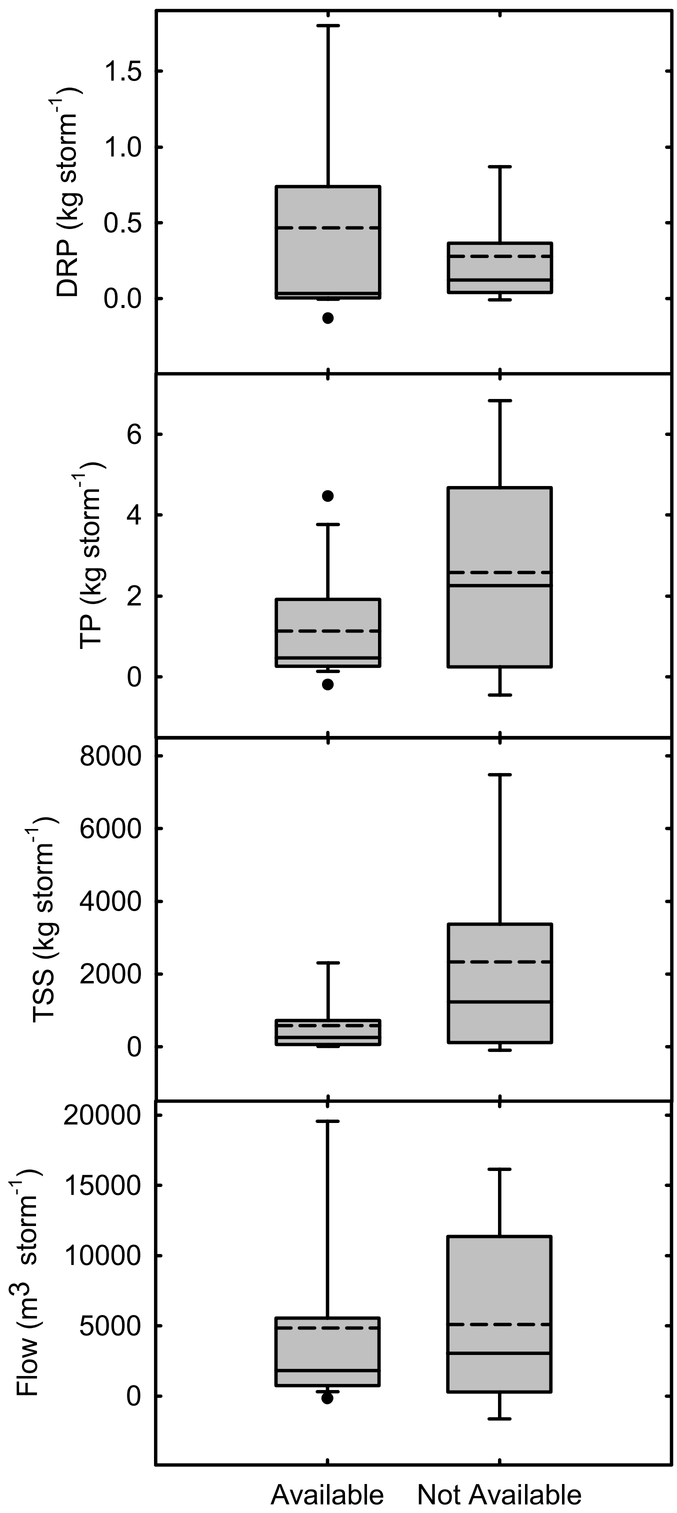


Figure 3.6. Daily loads of E. coli during base flow in streams draining pastures G5G6 and G8G9. Interior solid lines are medians and dash lines are means.



ig 3.7. Loads of Dissolved Reactive P (DRP), Total P (TP), Total Suspended Solids (TSS), and cumulative flow per storm event in pasture G5G6 with water troughs available or not. Interior solid lines are medians and dash lines are means.



ig 3.8. Loads of Dissolved Reactive P (DRP), Total P (TP), Total Suspended Solids (TSS), and cumulative flow per storm event from pasture G8G9 with water trough available or not. Interior solid lines are medians and dash lines are means.

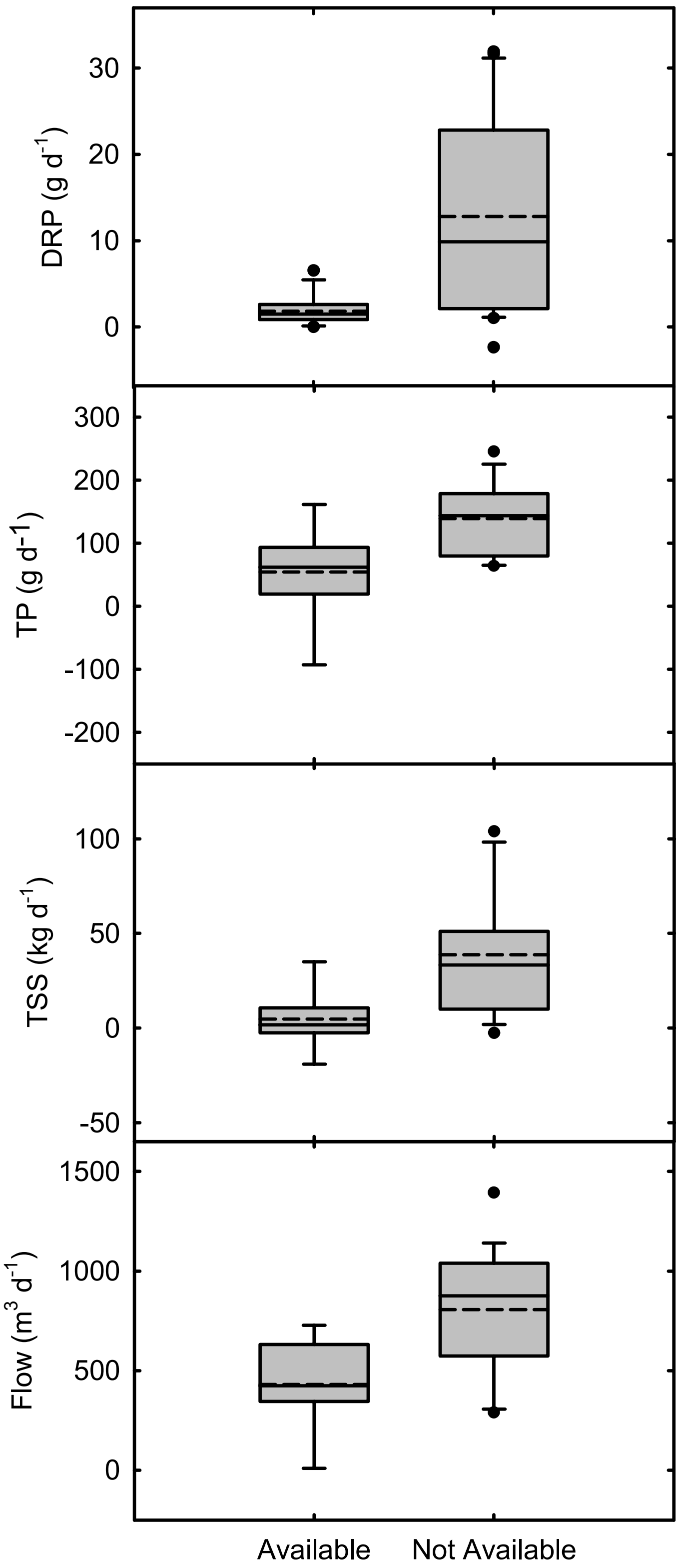


Figure 3.9. Daily loads of Dissolved Reactive P (DRP), Total P (TP), Total Suspended Solids (TSS), and daily base flow in the stream draining pasture G5G6 with the water trough available or not. Interior solid lines are medians and dash lines are means.

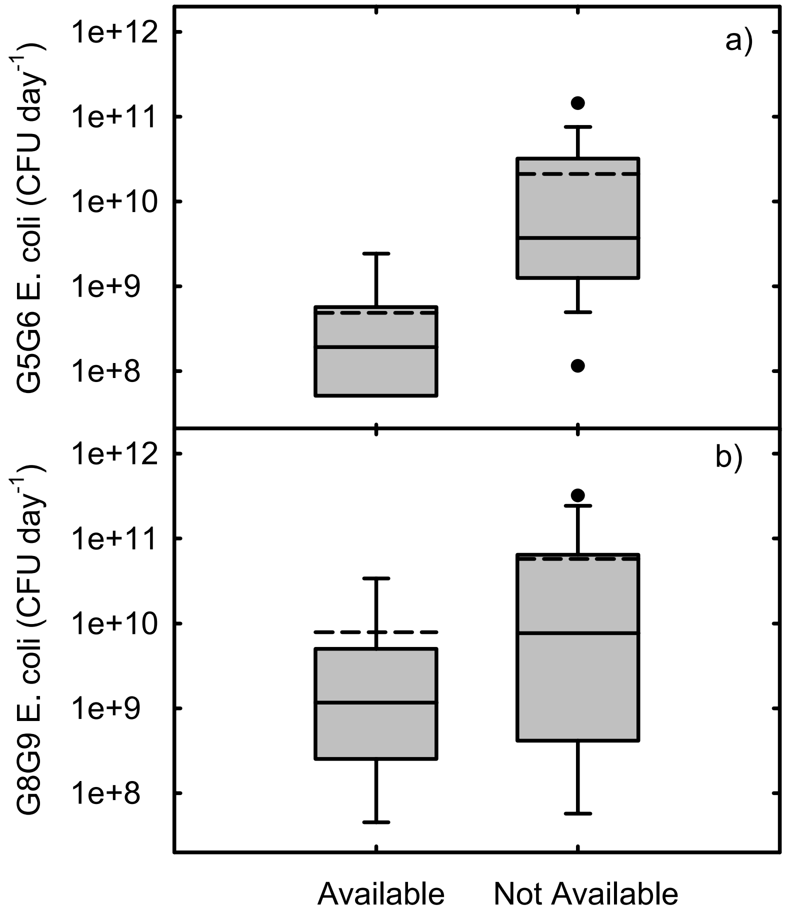


Figure 3.10. Daily load of E. coli during base flow in streams draining pastures G5G6 (a) and G8G9 (b) with water troughs available or not. Interior solid lines are medians and dash lines are means.

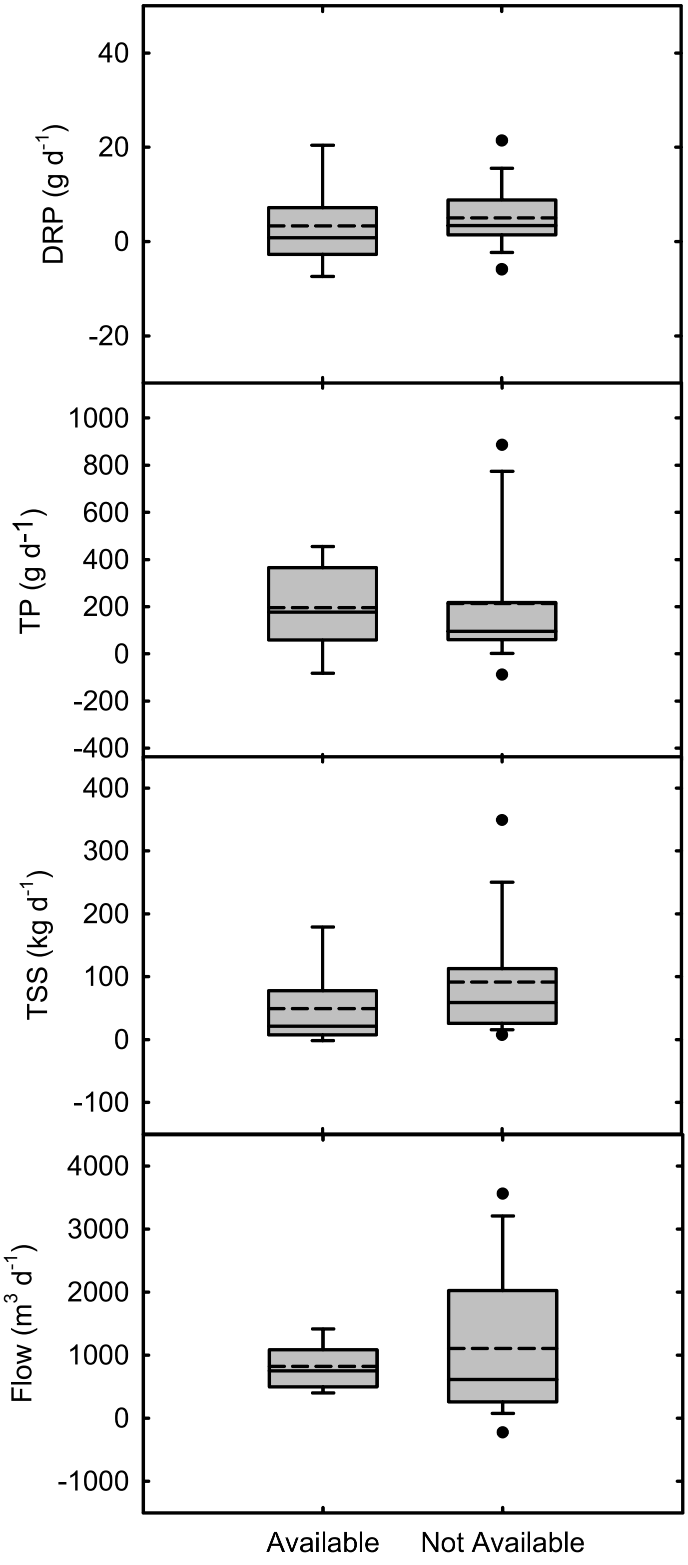


Figure 3.11. Daily loads of Dissolved Reactive P (DRP), Total P (TP), Total Suspended Solids (TSS), and daily base flow in the stream draining pasture G8G9 with the water trough available or not. Interior solid lines are medians and dash lines are means.

CONCLUSION AND IMPLICATIONS

From the behavior study, it was determined cattle spent between 5 and 10% of the day in the riparian area during warm months and less time during cold months, which leads to the conclusion their response, is in part a function of monthly THI. It was shown that if available, cattle sought shade when they used the riparian area. Cattle spent the maximum amount of time in the riparian area between the hours of 11:00 am and 1:00 pm. There was a linear relationship between cattle use of the riparian area and hourly THI between 5:00 am 1:00 pm. However, after 1:00 pm, cattle use of the riparian area ceased to respond linearly to hourly THI. The amount of time cattle spent in the riparian area was decreased by the presence of a water trough and abundant shade away from the stream. Cattle responses to these factors suggest water trough installation and abundant non-riparian shade may be two possible BMPs that could lessen the impact of grazing cattle on surface water quality. A variable that may have affected significantly our results is the presence of endophyte-infected tall fescue. As this forage has been shown to increase the core body temperature of mammals, the level of endophyte infection in a pasture could be a major factor in the amount of time cattle spend in riparian areas attempting to maintain homeostasis by cooling themselves in the water. Therefore, different results may be obtained in endophyte free or novel endophyte infected tall fescue.

The results of the water quality study clearly show that grazing cattle in pastures with unfenced streams contributed significant loads of DRP, TP, and TSS to surface waters during storm events and base flow. The loads contributed from the pastures appeared to be a function of shade distribution and water trough condition. In a pasture with the majority of shade in close proximity to the stream, the effect of grazing cattle on storm flow loads was more detrimental than in a pasture where most of shade was away from the stream. The increase of contaminant load appeared to be a direct response to the amount of time cattle spent in or near the riparian area. During base flow, the opposite relationship was noted, which was attributed to a constant flushing of contaminants from the pasture with abundant non-riparian shade. The reduction of stream contamination during base flow and storm events could be further observed during times when the water trough was closed. Cattle forced to the stream to drink in pastures with limited non- riparian shade tend to linger in the riparian areas longer than cattle with abundant non-riparian shade, thus increasing contaminant loads. The results of this study indicate that potential BMPs to reduce nutrient and sediment contamination from beef-cattle-grazed pastures would be to build or encourage shade development away from the stream, and to provide cattle with an alternative watering source away from the stream.

The implications from this study suggest that there are effective BMPs other than stream fencing, which have the potential to reduce the amount of surface water contamination from cattle operations. Therefore, livestock producers now have the ability to choose which BMPs will best fit their management practices and economic status. County extension agents and environmental consultants now have a reference to the effectiveness of two BMPs, and therefore can make recommendations to their clients as to which might be most effective in alleviating water quality problems on their particular farms.

Nutrient modelers will benefit from several aspects of this study. First and foremost, this study has demonstrated that the EPA's Bacteria Tool is over estimating the amount of time cattle are spending in the stream. From this study, nutrient modelers have literature to aid them in calibrating the Bacteria Tool. Such literature was lacking before, as this is the first long-term study that has examined the amount of time cattle spend in riparian areas during several crucial times during the year. Secondly and more importantly, nutrient modelers now have an empirical model that uses measurable heat stress data (temperature and humidity) to predict the amount of time cattle spend in streams. This newly developed relationship between heat stress and cattle behavior may be integrated into SWAT or another watershed model as a means of determining the amount of time cattle spend in the stream, which should translate to a more accurate modeling of bacteria and nutrient inputs from cattle-grazed pastures. Finally, from this study, nutrient modelers have literature to refer to in terms of evaluating the effectiveness of water troughs and non-riparian shade as two BMPs.

Finally, on a nation-wide scale, more accurate nutrient and bacteria models should translate to more accurate TMDL recommendations from regulatory agencies. However, more research is needed in the area of cattle behavior and water quality before wide-scale TMDL recommendations are made, as cattle response in other ecoregions of the United States may not respond in the same manner as cattle in the Georgia Piedmont.

APPENDIX

APPENDIX A

EFFECTS OF FENCED RIPARIAN ZONES ON STREAM MORPHOLOGY AND HABITAT[1]

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[1] H.L. Byers. To be submitted to *Journal of Environmental Quality*

Abstract

A study was conducted at The Central Georgia Branch Station in Eatonton, GA to examine the effects of a fenced riparian zone on streambed morphology in streams draining three Piedmont cattle pastures. For that purpose I conducted a pebble count and grab sample sieve analysis. Also, the effects of a fenced riparian zone on stream quality were examined using The Stream Visual Assessment Protocal (SVAP) and The Rapid Bioasssessment Protocol (RBP). Pebble count data were collected using a 50-cm diameter circular frame on samples taken along a randomly placed transect in each reach. Sieve analysis samples were taken from geomorphological and ecological important areas, dried at 100°C, and sieved with a 2-mm sieve. The SVAP and RBP scores were generated based on their respective instructions. The pebble count data were analyzed using the model proposed by Bevenger and King (2001). Sieve analysis, SVAP, and RBP data were analyzed with SAS. Based on pebble count data, the intermediate axis size of pebbles in stream reaches with a fenced riparian zones were significantly ($p< 0.05$) larger than reaches without a fenced riparian zone. With specific respect to the 2-mm and 4-mm size fraction, fenced riparian zones had significantly lower concentrations of the 2-mm and 4-mm size fraction at ($p< 0.01$) and ($p< 0.05$), respectively. Streambed sieve analysis results confirmed the results obtained in the pebble count, as fenced stream reaches had a significantly ($p< 0.05$) lower percent <2mm size fraction than the unfenced stream reaches. SVAP and RBP scores were significantly ($p< 0.01$) higher in stream reaches with a fenced riparian zone.

Introduction

Background

Livestock grazing affects the stream hydrology, stream morphology, and soil properties as well as vegetation and wildlife living by or in streams (Belsky et al., 1999). Contaminants such as N, P, and bacteria from animal grazing enter the watershed and can impose health risk to organisms on a basin-wide scale. The United States Geological Survey (USGS) National Quality Assessment surveyed 120 agricultural watersheds and found that the P concentration in 80% of the watersheds exceeded EPA standards (USGS, 2001).

The majority of watersheds in the Piedmont of the Southeastern United States are composed of Ultisols that form on rolling hills with slopes varying from 3% to 15% (Franklin et al., 1999). Ultisols are unfertile and have thick Bt layers with high clay content and low pH. Decades of cotton farming and soil mismanagement have left the vast majority of Piedmont soils unfertile, forcing current Piedmont farmers to migrate from row crop agriculture to cattle farming. In the Piedmont region, most of the Bt clay is kaolinite (West et al., 1998), a 1:1 clay with a low cation exchange capacity (CEC) of 3-20 $cMol_c\ kg^{-1}$ (Karathanasis et al., 1986) and an anion exchange capacity (AEC) of 0.03-1.91 $cMol_c\ kg^{-1}$ (Grove et al., 1982). The combination of low fertility, low CEC and AEC, steep slopes, and tendency for Ultisols to channelize flow make studying riparian zones in the Piedmont important to ensure quality water in the watersheds for as long as cattle growers continue to raise cattle in the region.

In order to build a riparian zone in the Piedmont, cattle access to the stream must be prevented. Fencing can accomplish this and perform two crucial functions. First, the fence keeps the cattle a certain distance from the stream. Since cattle can not physically get near the stream, they can not defecate near the stream, thus reducing the amount of stream contamination. Second, the fence allows for the sustainable growth of vegetation, thus reducing the amount of runoff that reches the stream even more. Recent studies show that a vegetative buffer zone separates contaminated water from direct contact with the stream, and decreases the amounts of contaminants (Lowrance et al., 1984; Lowrance, 1992; Yates and Sheridan, 1983). Pastures cannot have a vegetative riparian filter strip without a fence, as cattle would deposit feces directly in the stream and eventually destroy the riparian area; however, current research has noted the effectiveness of riparian zones by examining the combined influence of the fence and vegetative buffer on reducing runoff contamination (Line et al., 2000). In this study, the combined effects of fencing and riparian zones on the morphology and ecological health of three streams in the Piedmont of the United States was examined.

Purpose and Site Description

This study was conducted at the Central Research and Education Center (33^{o} 24'north longitude, 83^{o}29' west latitude, 150 m elevation) in Eatonton, GA. The study involved the analysis of three streams, referred to as 1, 2, and 3. Stream 1 drains pasture 1, which is 46.4 ha, stream 2 drains pasture 2, which is 41.0 ha, and stream 3 drains pasture 3, which is 46.4 ha (Fig A.1). Pastures 1, 2, and 3 each are divided by a fence into two paddocks: an upper paddock (a) and a lower paddock (b). Stream reaches draining paddocks 2a and 3a have a fenced riparian zone. The fence was built in 1993, and the entire length of stream 2 and 3 were ditched at this time to improve drainage of the pastures. The stream 2a riparian zone is 12 meters wide and is dominated by sweetgum, sumac, and briars, and the stream 3a riparian zone is 4 meters wide and is dominated by briars and small pine trees. Consequently, the stream lengths in 2b and 3b are not fenced allowing cattle free access to the stream; therefore, the riparian zone is absent, or at least dominated by forage grass, which has been shown to provide a minimal amount of filtration (Groffman et al., 1991). The entire stream length (1a&1b) in pasture 1 has been fenced for 40 years, which has created a mature riparian zone that is 24 meters wide and dominated by beach and pine trees as well as ungrazed fescue. The experimental station raises Angus (*Bos Taurus)* cow/calf pairs on all three pastures with a stocking rate of one cow/calf pair per ha. It is important to note that in all three streams, the slopes of the surrounding paddocks are similar.

Methods

Pebble Count

To study the effects of fenced riparian zones on streambed morphology, a pebble count was conducted. To collect pebble count data, a frame of 50-cm diameter was placed on the streambed and the mean pebble size viewed most often within the frame was recorded. A total of 120 samples were taken in reaches with a fenced riparian zone (1a&b, 2a, and 3a) and 60 samples in the unfenced reaches (2b&3b). The samples were taken along a transect that was 20 times the stream width and was randomly started within each reach. The transect was placed in the center of the streambed in each paddock.

Sieve Analysis

In addition to a pebble count, a sieve analysis of the streambed was conducted to quantify streambed morphological effects of riparian zones. To collect this data, 200 ml grab samples were taken from the center of the streambed at 6 equal intervals in each of the 6 reaches using the same transect used for collecting pebble count data, yielding 24 samples for the reaches with a fenced riparian zone and 12 samples for the unfenced reaches. The samples were dried at 105 °C for 24 hours. The dried aggregates of sample were broken up with a rolling pin and were sieved with a 2-mm sieve to determine the percent mass of the <2 mm size fraction.

Visual Assessments

To evaluate the overall habitat health of the three streams, two common visual assessment protocols, the Stream Visual Assessment Protocol (SVAP) (Newton et al., 1998) and The Rapid Bioasssessment Protocol (RBP) (Barbour et al., 1999) were used. Each protocol was performed along the same transect used in the pebble count and sieve analysis.

Statistical Analysis

For the purpose of this study, the data collected in the reaches with a fenced riparian zone were combined and served as the control. Likewise, data from unfenced reaches were combined and served as the experimental streams. To analyze the pebble count data, the model proposed by Bevenger and King, (2001) was used, which is designed to use pebble count data to assess watershed cumulative effects. Sieve analysis and visual assessment data were analyzed with SAS.

Results and Discussion

Pebble Count

Based on the model proposed by Bevenger and King, (2001), intermediate axis size of pebbles in stream reaches with a fenced riparian zones were significantly ($p< 0.05$) larger than reaches without a fenced riparian zone (Table A.1). With specific respect to the d”2mm and 4mm size fraction, fenced riparian zones had significantly lower concentrations of these size fractions at ($p< 0.01$) and ($p< 0.05$), respectively. The cumulative particle size distribution was plotted on a log scale against percentage finer (Fig A.2). It becomes clear that the unfenced streams lack complexity in pebble size, since over 90% of the particles are smaller than 1–2mm. Fenced streams in this study were more complex and had a higher variety of pebble sizes than the unfenced reaches, so fenced riparian reaches have the potential to support a greater diversity in organisms.

Owens et al. (1996) noted that within 5 years after fencing an area in Ohio dominated by Ultisols, the annual sediment concentrations of the draining stream decreased by nearly 60% and soil loss from the pasture decreased by 40%. Magilligan and McDowell (1997) found very similar results as they examined the effects of grazing exclusion on stream morphology on three streams in Oregon. With respect to pebble size, the researchers noted a slight increase in pebble size in half of the areas that were restricted to cattle access (Magilligan and McDowell, 1997). Myers and Swanson (1996) noted a similar trend in their study, as the researchers evaluated three streams draining grazed pastures. The three pastures had been allowed to rest for 1, 2, and 14 years, respectively, and the researchers discovered a direct correlation between increased pebble size and time livestock are not allowed access to the stream.

My research agrees with the findings of Ownes et al., Magilligan and McDowell, and Myers and Swanson. When cattle are restricted from access to streams by a fenced riparian zone, the intermediate axis size of pebbles in the streambed will increase. This is contradictory to my original proposal, were I proposed that as cattle trample in the stream they stir up the finer sediment and suspend the disturbed particles in the water column; therefore, the fine sediments should have washed downstream leaving coarser material behind, whereby an increase in coarse material should be observed in the unfenced reaches. Two occurrences could account for this incorrect proposal. First, it is possible that indeed, cattle are mechanically suspending and washing downstream fine streambed particles via the water column as first proposed. However, if sediment addition into the stream by bank degradation and runoff is greater than the amount of sediment leaving the stream; unfenced reaches should have a lower pebble size. The second possibility suggests that as cattle wade around the stream, they are mechanically breaking the large pebbles into finer pebbles at the same time probably burying larger pebbles under fine sediment.

Streambed Sieve Analysis

Streambed sieve analysis results confirmed the results obtained in the pebble count. At ($p< 0.05$), fenced stream reaches had a lower percent <2mm size fraction than the unfenced stream reaches (Table A.2).

SVAP

As expected, SVAP scores were significantly ($p< 0.01$) higher in stream reaches with a fenced riparian zone (Table A.3). From the start of this study, it is assumed that the fenced and unfenced stream reaches are identical, as they have the same geomorphological history;

therefore, the fenced stream reaches should score higher on only one section of the SVAP, the section evaluating riparian zone width. Any differences in scores of the remaining sections of the SVAP are due solely to the effects of the fenced riparian zone. If this assumption is true, several interesting trends evolve from the effects of a fenced riparian zone on runoff filtration, stable habitat creation, and cattle exclusion. It is a well established fact that riparian zones perform a large amount of filtration of nutrient and sediment contaminants in runoff, and this is reflected in the SVAP scores for “Water Appearance,” “Nutrient Enrichment,” and “Riffle Embededness.” In the fenced stream reaches, the scores for these three categories are significantly ($p< 0.05$) higher than the scores in unfenced reaches. Secondly, fenced riparian zones greatly benefit aquatic life in the stream by creating and maintaining a stable habitat for organisms, and these effects are reflected in the SVAP scores for “Canopy Cover,” “Invertebrate Habitat,” and “In Stream Fish Cover.” In the fenced stream reaches, the scores for these categories are significantly ($p< 0.01$) higher than the scores for the unfenced reaches. Finally, the SVAP scores reflect the effects of cattle exclusion on stream quality. These effects are reflected in the SVAP scores for “Bank Stability,” “Pools,” and “Manure Presence.” In the fenced stream reaches, the scores for these areas are significantly ($p< 0.01$) higher than the scores in the unfenced reaches. “Channel Condition,” “Hydraulic Alteration,” and “Barriers to Fish Movement” are more strongly influenced by direct human alteration rather than the effect of fenced riparian zone. Both the fenced and unfenced reaches of streams 2 and 3 scored low on these sections, as the two streams were dredged nine years ago.

Uncontrolled grazing in the Central Basin of Tennessee demonstrated that allowing cattle free access to the stream can increase gross bank erosion six-fold when compared to a protected reach (Trimble, 1994). Cattle on this stream caused major mechanical breakdown of the banks which caused the banks to become vulnerable to overflow conditions and susceptible to hydraulic stream bank scour. Magilligan and McDowell (1997) discovered that when cattle are removed from a riparian area the bankfull and low width areas decrease and they observed a remobilization of the bed into more pool area. Belsky et al. (1999) reviewed the literature and found that cattle in the Western United States influence streams by increasing channel depth and width, decreasing channel stability during floods, decreasing gravel presence in stream bed, reducing streambank stability, increasing laid back streambank angle, reducing streambank undercuts, decreasing meanders, decreasing the number and quality of pools, and increasing algae growth. Cattle alterations to the riparian zone lead to an increase in bare ground, an increase in soil erosion, a decrease in litter layer, an increase in compaction, a decrease in infiltration, and a decrease in fertility (Belsky et al., 1999). My research agrees with the conclusions of Trimble, Magilligan and McDowell, and Belsky et al. By restricting cattle access to a stream by building a fenced riparian zone, stream health is improved.

RBP

The RBP scores mirrored the SVAP scores, as stream reaches with a fenced riparian zone scored significantly ($p< 0.01$) higher than the unfenced stream reaches. The RBP evaluates the biological potential of a stream by examining stream habitats by evaluating the quality and quantity of potential habitats for aquatic life rather than the overall quality of the stream. It is difficult to draw conclusions about fenced riparian zones with the RBP, as many of the categories examined by the RBP are solely influenced by natural processes. However, it is important to note thats the RBP is biased against non-native species as riparian filtration agents. Japanese Privet (*Ligustrum japonicum*) and Japanese Honeysuckle (*Lonicera japonica)* are prevalent in all three stream reaches, so even though these plants are beneficial to the riparian zone, the RBP score for “Riparian Zone” is low for these reaches.

Conclusion

Intermediate axis size of pebbles in stream reaches with a fenced riparian zone were significantly ($p< 0.05$) larger than reaches without a fenced riparian zone. With specific respect to the d”2mm and 4mm size fraction, fenced riparian zones had significantly lower concentrations of the d”2mm and 4mm size fraction at ($p< 0.01$) and ($p< 0.05$), respectively.

Streambed sieve analysis results confirmed the results obtained in the pebble count. At ($p < 0.05$), fenced stream reaches had a lower percent of <2mm size fraction than the unfenced stream reaches. SVAP and RBP scores were significantly ($p < 0.01$) higher in stream reaches with a fenced riparian zone. Although a fenced riparian zone is crucial in maintaining proper water quality in cattle grazed pastures, more research needs to be conducted to investigate other management practices. More studies are needed to detect seasonable variations and influences on these results.

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Table A.1. Fenced and unfenced stream pebble count (mm)

	Fenced Streams				Unfenced Streams	
Sample	1A	1B	2A	3A	2B	3B
1	1	3	1	2	1	1
2	25	3	1	2	2	1
3	3	10	1	3	1	1
4	1	3	1	2	1	1
5	1	3	1	2	1	1
6	3	1	1	3	2	1
7	1	3	1	2	1	1
8	3	5	1	2	1	1
9	2	1	1	3	1	1
10	1	1	1	3	1	1
11	6	2	1	2	2	1
12	2	2	1	2	2	1
13	2	1	1	3	2	1
14	3	1	1	3	2	1
15	1	1	1	2	1	1
16	3	4	1	2	1	1
17	2	5	1	2	1	1
18	3	5	1	2	1	1
19	1	3	1	3	1	1
20	1	4	1	2	1	1
21	1	4	1	3	1	1
22	1	5	1	2	2	1
23	2	2	1	2	1	1
24	2	3	1	2	1	1
25	2	4	1	2	1	1
26	4	1	1	3	2	1
27	1	1	1	2	1	1
28	1	1	1	2	1	1
29	1	4	1	3	1	1
30	1	2	1	2	1	1

Table A.2. Streambed sieve analysis

Fenced Streams			
Stream	Total Sample Weight (g)	Weight of <2mm	Percent <2mm
1A	50.29	0.43	0.86%
1A	110.22	52.97	48.06%
1A	183.94	114.73	62.37%
1A	249.42	96.22	38.58%
1A	155.09	77.25	49.81%
1A	121.13	71.32	58.88%
Total	870.09	412.92	47.46%
1B	212.36	84.49	39.79%
1B	180.42	74.12	41.08%
1B	168.58	108.41	64.31%
1B	223.59	152.02	67.99%
1B	219.13	139.31	63.57%
1B	223.93	138.89	62.02%
Total	1228.01	697.24	56.78%
2A	219.7	181.73	82.72%
2A	242.39	204.42	84.34%
2A	176.7	138.73	78.51%
2A	220.4	182.43	82.77%
2A	169.69	131.72	77.62%
2A	204.44	166.43	81.41%
Total	1233.32	1005.46	81.52%
3A	184.47	126.49	68.57%
3A	204.66	139.94	68.38%
3A	199.15	87.6	43.99%
3A	228.06	111.88	49.06%
3A	176.95	136.19	76.97%
3A	161.42	116.44	72.13%
Total	1154.71	718.54	62.23%

Unfenced Streams			
Stream	Total Sample Weight (g)	Weight of <2mm	Percent <2mm
2B	173.53	172.45	99.38%
2B	139.56	130.44	93.47%
2B	127.02	125.76	99.01%
2B	187.33	186.25	99.42%
2B	173.13	164.12	94.80%
2B	132.35	116.26	87.84%
Total	928.92	895.28	96.38%
3B	189.11	188.73	99.80%
3B	187.56	142.88	76.18%
3B	165.46	161.25	97.46%
3B	230.94	222.31	96.26%
3B	217.38	171.01	78.67%
3B	183.05	176.86	96.62%
Total	1173.5	1063.04	90.59%

Table A.3. Stream Visual Assessment Protocol scores

	Fenced Streams				Unfenced Streams	
	1A	1B	2A	3A	2B	3B
Channel Condition	8	9	7	5	4	5
Hydraulic Alteration	5	5	9	5	3	5
Riparian Zone	10	10	10	10	1	1
Bank Stability	7	7	8	7	2	2
Water Appearance	9	6	5	6	5	2
Nutrient Enrichment	6	2	2	5	2	2
Barriers to Fish	7	7	5	5	5	5
In Stream Fish Cover	7	7	8	6	3	4
Pools	3	5	1	5	2	2
Invert. Habitat	9	8	6	9	5	2
Canopy Cover	7	9	3	8	1	1
Manure Presence	8	8	4	4	1	1
Riffle Embededness	5	4	1	5	1	5
Average	7.00	6.69	5.31	6.15	2.69	2.85
Standard Deviation	1.92	2.25	3.01	1.82	1.60	1.68

Table A.4. Rapid Bioassessment Protocol scores

	Fenced Streams				Unfenced Streams	
	1A	1B	2A	3A	2B	3B
Substrate Cover	14	16	9	9	10	5
Pool Substrate	13	15	11	12	10	5
Pool Variability	10	6	5	9	6	8
Sediment Deposition	6	5	14	9	4	9
Channel Flow Stat.	11	15	9	6	9	6
Channel Alteration	12	12	10	8	8	8
Channel Sinuosity	13	14	13	1	1	1
Bank Stability (LB)	7	8	7	7	2	4
Bank Stability (RB)	8	8	8	7	2	4
Riparian Zone (LB)	5	5	5	6	3	2
Riparian Zone (RB)	7	5	5	5	3	2
Riparian Width (LB)	5	4	5	2	1	1
Riparian Width (RB)	8	4	5	2	1	1
Average	11.90	11.70	10.60	8.30	6.00	5.60
Standard Deviation	2.51	4.19	2.88	3.83	3.23	2.72

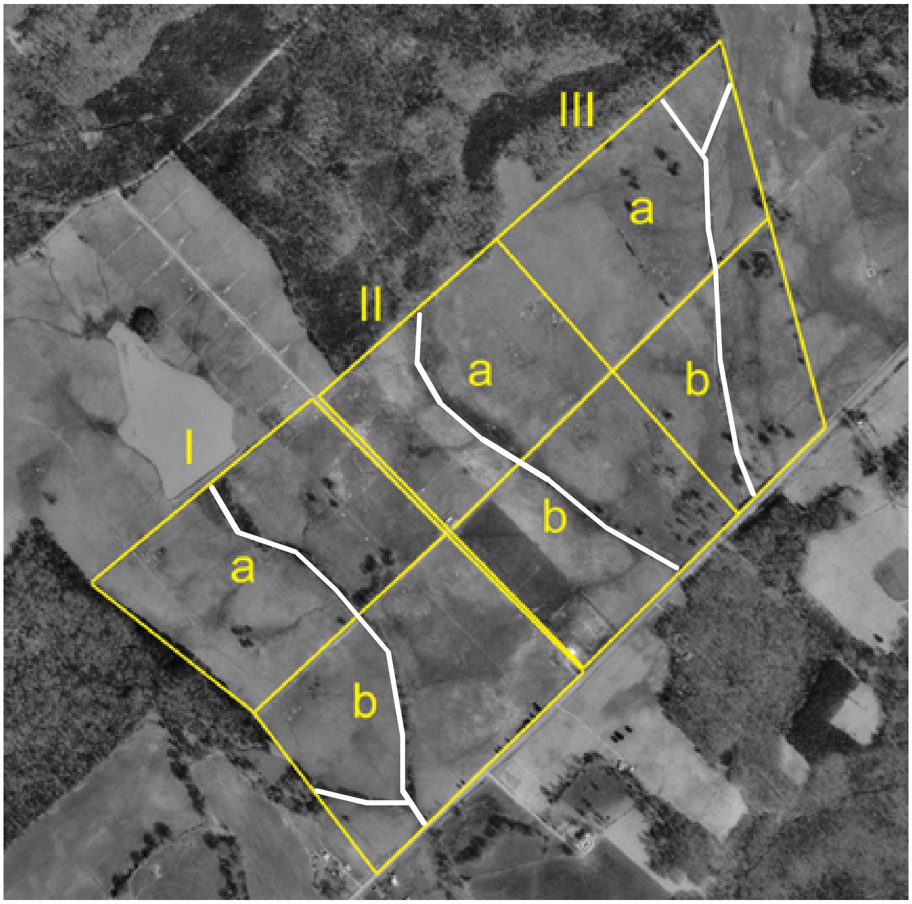

Figure A.1. Map of three pastures at the Central Research an Education Center. Fences are outlined in yellow and streams are outlined in white.

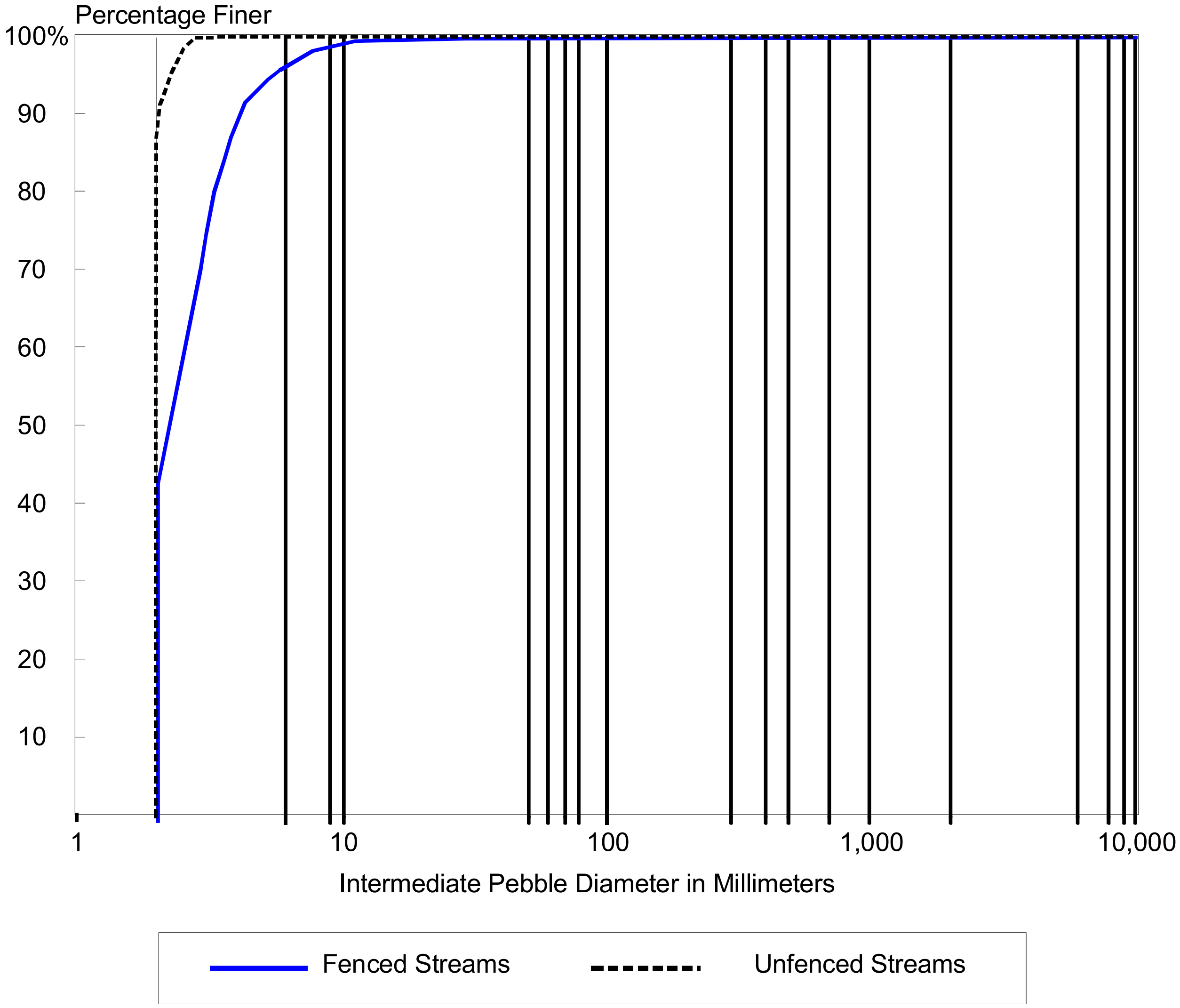

Fig A.2. Cumulative Particle Size Distribution