Grazing Management and Microclimate Effects on Cattle Distribution Relative to a Cool Season Pasture Stream

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Abstract

Because of concerns about the impact of grazing management on surface water quality, a 3-yr study was conducted to determine grazing management and microclimate impacts on cattle distribution relative to a pasture stream and shade. Three treatments, continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), and rotational stocking (RS), were evaluated on six 12.1-ha cool-season grass pastures stocked with 15 fall-calving Angus cows (*Bos taurus* L.) from mid-May through mid-October of each year. On 2 d · mo⁻¹ from May through September of each year, a trained observer in each pasture recorded cattle position and activity every 10 min from 0600 to 1800 hours. In years 2 and 3, position of one cow per pasture was recorded with a Global Positioning System (GPS) collar at 10-min intervals 24 h · d⁻¹ for 2 wk · mo⁻¹ from May through September. In week 2 of collar deployment in May, July, and September, cattle had access to off-stream water. Ambient temperature, black globe temperature, relative humidity, and wind speed were recorded at 10-min intervals and temperature humidity (THI), black globe temperature humidity (BGTHI), and heat load (HLI) indices were calculated. Based on GPS collars, mean percentage of time cows in CSU pastures were in the stream (1.1%) and streamside zone (10.5%) were greater ($P < 0.05$) than cows in CSR (0.2% and 1.8%) or RS (0.1% and 1.5%) pastures. Based on GPS collar data, off-stream water did not affect the percentage of time cattle in CSU or CSR pastures spent in the stream. Probabilities that cattle in CSU and CSR pastures were in the stream or riparian zones increased ($P < 0.05$) as ambient temperature, black globe temperature, THI, BGTHI, and HLI increased. Rotational stocking and restricted stream access were effective strategies to decrease the amount of time cattle spent in or near a pasture stream.

Resumen

Debido a preocupaciones sobre el impacto del manejo del pastoreo sobre la calidad del agua superficial, se realizó un estudio de 3 años para determinar el impacto del manejo del pastoreo y del microclima sobre la distribución del ganado en relación a la sombra y la corriente de agua. Se utilizaron tres tratamientos: Pastoreo continuo—sin restricción al acceso a la corriente de agua (CSU), pastoreo continuo con restricciones al acceso a la corriente de agua (CSR), y pastoreo rotacional; se evaluaron en seis potreros de 12.1 ha de gramíneas de crecimiento invernal utilizando 15 vacas Angus (*Bos taurus* L.) de mediados de Mayo hasta mediados de Octubre en cada año. En el 2 d-mes de Mayo hasta Septiembre de cada año un observador entrenado en cada potrero registró la posición y la actividad del ganado cada 10 minutos desde 0600 hasta las 1800 horas. En los años 2 y 3, se registró la posición y la actividad de una vaca/potrero utilizando collares con GPS a intervalos de 10 min cada 24 h-d-1 durante dos semanas-mes desde Mayo hasta septiembre. En la semana 2 de la implementación de los collares en Mayo, Julio, y septiembre el ganado tenía acceso a la corriente de agua. Temperatura ambiente, humedad relativa, temperatura de globo negro y velocidad del viento se registraron a intervalos de 10 minutos y humedad de temperatura (THI), la humedad de la temperatura del globo negro (BGTHI), y se calcularon los índices de carga de calor (HLI). Basados en los collares de GPS, la media del porcentaje del tiempo de las vacas en los potreros CSU que estuvieron en la corriente (1.1%), y en la zona de la corriente (10.5%) fue mayor ($P < 0.05$) que en vacas en CSR (0.2% y 1.8%) o en los potreros de RS (0.1% y 1.5%). Basándose en los datos de los collares de GPS, el agua fuera de la corriente no afectó el porcentaje del tiempo que el ganado en los potreros de CSU o CSR dedicó a la corriente. Las probabilidades de que el ganado en los potreros de CSU y CSR estuviera en la corriente o en las zonas ribereñas se incrementa ($P < 0.05$) conforme aumenta la temperatura ambiente, la temperatura del globo negro, THI, BGTHI, y HLI. El pastoreo rotacional, y el acceso restringido a la corriente son estrategias efectivas para disminuir la cantidad del tiempo que el ganado está cerca o en los potreros de corrientes.

Key Words: GPS, heat stress, off-stream water, rotational stocking, stabilized crossings

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INTRODUCTION

Livestock grazing has been implicated in the degradation of surface water quality (Council for Agricultural Science and Technology 2002; Alexander et al. 2008) and riparian ecosystems (Fitch and Adams 1998) in grazing lands. Poorly managed grazing may increase loading of sediment, nutrients, and pathogens in surface waters and change stream morphology (Fitch and Adams 1998; Byers et al. 2005). Grazing management has been shown to decrease amounts of sediment and phosphorus originating from upland portions of pastures and transported in surface runoff (Haan et al. 2006). However, much of the pollutants entering surface waters originate from areas near streams (Pionke et al. 2000) as a result of cattle congregating in these areas (Smith et al. 1992).

Abiotic factors, such as pasture topography and distance to water and biotic factors, such as forage quality and quantity, are the primary factors determining grazing distribution within a pasture (Bailey et al. 1996). Cattle use of riparian areas can also be influenced by temperature (Zuo and Miller-Goodman 2004). Uneven cattle distribution may result in overutilization of the riparian areas (DelCurto et al. 2005). Complete exclusion of cattle from pasture streams has been proposed as a method to limit potentially negative impacts of beef cattle grazing on surface water quality (Belsky et al. 1999; Line 2003). However, complete exclusion of cattle from streams is often not practical as cattle depend on these riparian areas for grazing, drinking, and regulation of body temperature (Zuo and Miller-Goodman 2004; Ballard and Krueger 2005).

Altering the temporal/spatial distribution of grazing cattle by use of rotational stocking (Lyons et al. 2000; Sovell et al. 2006) improved stream access points (Agouridis et al. 2005), and off-stream water and nutritional supplementation sites (Sheffield et al. 1997; McInnis and McIver 2001; Porath et al. 2002; Bailey and Jensen 2008) have been proposed as alternatives to complete exclusion to reduce potentially negative impacts of cattle on streams while allowing use of riparian areas. Sovell et al. (2006) reported greater bank erosion, turbidity, and fecal coliform concentrations in streams in continuously stocked than rotationally stocked pastures. The addition of an off-stream water source has been shown to decrease the percentage of time cattle spent in the riparian area by 40% to 96% depending on season (Byers et al. 2005).

The effects of environmental temperature and humidity on the behavior and performance of feedlot cattle and confined dairy cattle have been studied extensively (Castaneda et al. 2004; Berman 2005). Several indices, which combine multiple weather variables, have been developed to better predict the occurrence of heat stress in livestock and humans than temperature alone (Moran et al. 2001; Epstein and Moran 2006; Mader et al. 2006). Indices that included black globe temperature in place of ambient temperature were better predictors of heat stress in cattle than indices that did not include black globe temperature (Yamamoto et al. 1994; Mader et al. 2006). While indices using black globe temperature seem to be more sensitive predictors of heat stress in cattle, these indices have not been utilized to predict the temporal/spatial distribution of grazing cattle in pastures.

The objective of the current study was to determine the impacts of grazing management and microclimate on cattle use of stream channels, riparian areas, uplands, and shade.

Figure 1. Pasture layout at the Rhodes Research Farm.

MATERIALS AND METHODS

Site Description and Pasture Management

For 3 yr (2005–2007), six 12.1-ha cool-season grass pastures, each bisected by a 141-m stream segment, were grouped into two blocks and assigned one of three grazing management treatments (Fig. 1). Pastures were located at the Iowa State University Rhodes Research farm in central Iowa (lat 42°00'N, long 93°25'W) and primarily contained a mixture of smooth brome grass (*Bromus inermis* L.) and reed canarygrass (*Phalaris arundinacea* L.) with lesser proportions of tall fescue (*Festuca arundinacea* Schreb.), Kentucky bluegrass (*Poa pratensis* L.), and legumes. Annual precipitation was 915 mm, 806 mm, and 1 021 mm in 2005, 2006, and 2007, respectively (30-yr average annual precipitation, 889 mm; National Oceanic and Atmospheric Administration 2005, 2006, 2007). Tree cover in the pastures and the streamside zones (the pasture areas within 33 m of the bank) varied between pastures, resulting in differences in shade distribution among pastures. Tree cover, measured at the tree dripline, in the pastures ranged from 1.4% to 13.8% of the pasture area, and tree cover in the streamside zone ranged from 3.6% to 23.7% of the streamside zone. Pastures with greater shade in the streamside zone also had a greater occurrence of shade in the rest of the pasture.

Treatments included continuous stocking with unrestricted stream access (CSU), continuous stocking with stream access

restricted to a 4.9-m wide crushed rock-polyethylene webbing (Presto Geosystems, Appleton, WI)-geofabric crossing with 11.3-m access ramps (CSR), and five-paddock rotational stocking with one paddock in the functional riparian zone (RS). Each treatment was replicated twice. Grazing was not allowed in approximately 0.9 ha that were fenced as riparian buffers on either side of the crossings in CSR pastures. Riparian paddocks in the RS pastures were 0.91 ha and stocked until forage sward height decreased to a minimum of 10 cm (Clary and Leininger 2000), as determined by a falling plate meter ($4.8 \text{ kg} \cdot \text{m}^{-2}$; Haan et al. 2007), or for a maximum of 4 d. Upland paddocks in RS pastures were 2.78 ha and stocked to allow for 50% forage removal in each rotation, as estimated with a falling plate meter ($4.8 \text{ kg} \cdot \text{m}^{-2}$; Haan et al. 2007). The riparian buffer in the CSR pastures and the riparian paddock in the RS pastures extended to approximately 33 m on either side of the stream. Each pasture was stocked with 15 fall-calving Angus cows (*Bos taurus* L.; initial body weight [mean $\pm$ SE] $648 \pm 72 \text{ kg}$, $577 \pm 53 \text{ kg}$, and $621 \pm 56 \text{ kg}$, respectively) from mid-May through mid-October (157 d, 156 d, and 152 d, respectively) in 2005, 2006, and 2007.

Off-stream water sites, consisting of tanks with floats, were located in the pasture uplands on both sides of the stream, at a minimum distance of 240 m from the stream. In CSU and CSR pastures, off-stream water sites were fenced to control cattle access. Cattle were provided with a phosphorus-free mineral supplement in mineral feeders located adjacent to off-stream watering sites. Pastures received no fertilization for the duration of the study.

Cattle Distribution With GPS Collars

One cow per pasture was fitted with a Global Positioning System (GPS) collar (AgTraX; BlueSky Telemetry, Aberfeldy, Scotland) for approximately 2 wk in each month from May through September of each year. In 2005, GPS collar data sets were not complete due to mechanical failure, and, therefore, only 2006 and 2007 GPS collar data are presented. Collars recorded position at 10-min intervals $24 \text{ h} \cdot \text{d}^{-1}$ during the 2-wk period. Collar accuracy was tested in 2006 by placing collars in a fixed position, away from buildings and other obstructions, and recording position at 10-min intervals over a 36-h period. Mean horizontal error recorded by six AgTraX collars over the 36-h period was 7.7 m (SD 1.32 m). Data from GPS collars were imported into ArcGIS 9.1 (ESRI, Redlands, CA) to determine cattle location in relation to the pasture stream. For time periods in which GPS collars were unable to record cattle position, the position, less than 7% of readings, was assumed to be the same as the previous reading.

To test the effectiveness of off-stream water on altering cattle distribution in May, July, and September of 2006 and 2007, off-stream water tanks were made available to cattle in the CSU and CSR pastures during the second week of GPS collar data collection.

Cattle Activity and Distribution With Visual Observations

Visual observations of cattle distribution and activity were conducted from 0600 to 1800 hours on two consecutive days in May, June, July, August, and September in 2005, 2006, and 2007. Cows in CSU and CSR pastures did not have access to

off-stream water sites during visual observation days or the night prior to visual observations. One trained observer, equipped with a hand-held GPS receiver (GPS 72 Personal Navigator; Garmin Ltd, Olathe, KS), was located within each pasture. If the cow herd split into subgroups, the observer remained with the group that included the cow fitted with the GPS collar. Cow herd location, number of cattle present, number of cattle under shade, and the number of observed defecations and urinations were recorded at 10-min intervals.

Cattle location for both visual observation and GPS collar data was defined as within stream (Stream Zone), 0 m to 33 m from the stream edge (Streamside Zone), 33 m to 66 m from the stream edge (Transition Zone), and greater than 66 m from the stream edge (Upland Zone). The Stream Zone was mapped by slowly walking the length of the stream with a GPS collar (AgTraX, BlueSky Telemetry, Aberfeldy, Scotland) recording position at 30-s intervals. Stream channel was approximately 3 m wide. The Streamside Zone was approximately the same width as the riparian paddocks and buffers in the RS and CSR pastures, respectively. The Transition Zone included the remainder of the functional riparian area and the start of the uplands. The Stream Zone, Streamside Zone, Transition Zone, and Upland Zone were 1.1%, 6.1%, 6.1%, and 86.8% of the pasture area, respectively.

Microclimatic Measurements

Ambient temperature (Temp), black globe temperature (BGTemp), wind speed, and relative humidity were recorded at 10-min intervals using a data-logging HOBO weather station (Onset Comp Co, Bourne, MA) located in the riparian area in the center of the study site. A temperature humidity index (THI; Mader et al. 2006), black globe temperature humidity index (BGTHI; Mader et al. 2006), and heat load index (HLI; Gaughan et al. 2008) were calculated for every 10-min measurement as

$$\text{THI} = [0.8 \times \text{Temp}] + [(\text{RH}/100) \times (\text{Temp} - 4.4)] + 46.4$$

$$\text{BGTHI} = [0.8 \times \text{BGTemp}] + [(\text{RH}/100) \times (\text{BGTemp} - 14.4)] + 46.4$$

$$\text{HLI}_{\text{BGTemp} > 25} = 8.62 + [0.38 \times (\text{RH}/100)] + (1.55 \times \text{BGTemp}) - (0.5 \times \text{WS}) + [e^{2.4 - \text{WS}}]$$

or

$$\text{HLI}_{\text{BGTemp} < 25} = 10.66 + [0.28 \times (\text{RH}/100)] + (1.3 \times \text{BGTemp}) - \text{WS}$$

where RH = relative humidity, %; and WS = wind speed, $\text{m} \cdot \text{s}^{-1}$ (Temp and BGTemp, $^{\circ}\text{C}$).

To determine the impact of microclimate on cattle distribution and activity, cattle location data from both visual observation and GPS collar data were paired with microclimate data for each observation time. For each one unit increment of each microclimatic variable (Temp, BGTemp, THI, BGTHI, and HLI), the number of observations that a cow was in a given

zone was divided by the total number of observations at that temperature (1°C) or index unit (1 index unit) increment to determine the probability of a cow being in that zone at that microclimatic variable increment.

Statistical Analysis

Grazing management effects on cattle occupancy of the four pasture zones (Stream, Streamside, Transition, and Upland) using visual observation and GPS collar data were analyzed using the MIXED procedure of SAS (SAS 1999) for the periods when off-stream water was not available. Data were analyzed within each pasture zone by month and the model statement included treatment; pasture was the experimental unit. The effects of off-stream water on cattle occupancy of stream and streamside zones, using GPS collar data, in CSU and CSR pastures were analyzed using the MIXED procedure of SAS (SAS 1999). Data were analyzed within each pasture zone by month and the model statement included treatment, availability of off-stream water, and treatment by water availability interactions; pasture was the experimental unit. Multiple comparisons for variables with significant treatment effects were tested using the Tukey method, and significance was determined at $P < 0.05$ with a tendency for significance at $P < 0.10$. Least-squares means are presented in the text, figures, and tables.

To determine if observed cattle defecation or urination distribution patterns were similar to cattle distribution patterns, an odds ratio was calculated as the percent observed defecations or urinations divided by percent observations for each observation period within each pasture zone, resulting in 18 observations (3 yr $\times$ 2 replicates $\times$ 3 treatments) within each pasture zone. A t test (SAS 1999) was used to determine if this odds ratio differed from expected levels for each zone.

The LOGISTIC procedure of SAS (SAS 1999) was used to test the effect of climatic variables on the probability of cattle being in the shade or riparian zone. An odds ratio was calculated to determine the effect of a one-unit increase in the climatic variable (Temp, BGTemp, THI, BGTHI, and HLI) on cattle being in either the shade or riparian zone. The probability of cattle being in the riparian zone was based on GPS collar data while the probability of cattle being in shade was based on visual observation data. Rotationally stocked pastures were excluded from the analysis of climatic factors on cattle use of the riparian area or shade because cattle could not freely access the riparian zone and not all paddocks provided cattle access to shade. For this analysis, the riparian zone was the sum of the observations in the Stream and Streamside Zones. The climatic variable that best predicted cattle presence in either shade or riparian zone was determined using Akaike's Information Criteria (AIC; SAS 1999).

RESULTS AND DISCUSSION

Grazing Management Effects on Cattle Distribution and Activity

Pasture Management. The effects of management on cattle distribution patterns and activity within pastures have been studied by both visual observation methods (Gillen et al. 1984; Howery et al. 1998; Harris et al. 2007) and with GPS collar

technology (Agouridis et al. 2004; Ganskopp and Bohnert 2006; Bailey and Jensen 2008). In the current study, data from visual observations and GPS collars showed similar trends; however, there were differences in percentage of time cattle spent in Stream and Streamside Zones between the two methods.

Based on GPS collar data, cattle in CSU pastures spent more ($P < 0.05$) time in the Stream Zone in May (0.5%), June (2.1%), and August (0.6%) than did cattle in the CSR (0.1%, 0.1%, and 0.1%, respectively) or RS (0.0%, 0.0%, and 0.1%, respectively) pastures (Fig. 2A). Similarly, cattle in CSU pastures spent a greater ($P < 0.05$) mean percentage of time in the Streamside Zone in May (13.5%), June (10.7%), and July (11.0%) and tended to spend a greater ($P < 0.10$) percentage of time in this zone in August (7.5%) than did cattle in the CSR (1.2%, 1.7%, 2.5%, and 1.1%, respectively) or RS (0.5%, 0.5%, 0.4%, and 0.1%, respectively) pastures (Fig. 2B). Differences in cattle use of the Transition (Fig. 2C) and Upland (Fig. 2D) Zones were also observed between grazing management treatments in some months.

Data from GPS collars showed that cattle were present in the Stream and Streamside Zones of CSU pastures 1.2% and 10.6%, respectively, of the time averaged over the grazing season. The Stream and Streamside Zones are 1.1% and 6.1% of the available pasture area, indicating that when cattle had unrestricted access to the pasture stream they did not congregate in the stream but tended to favor the streamside over other pasture zones. Smith et al. (1992) reported cattle used the channel and flood plain area of a pasture to a greater extent than the relative contributions of those areas to the total pasture area; they attributed cattle preference for the riparian area to greater forage mass and quality and the availability of water. Cattle in the CSR and RS pastures did not overutilize the Streamside Zone relative to its fraction of the total pasture area. These data support the concept that management of riparian and upland portions of pastures separately will result in more uniform grazing, as suggested by Bailey (2005).

Similar to the results obtained with GPS collars, cattle managed by CSU spent a greater ($P < 0.05$) percentage of time in the Stream (Fig. 3A) and Streamside (Fig. 3B) Zones in May through August than cattle managed by either CSR or RS during these months, based on visual observations. During the months of May through August cattle were observed to be in the Stream or Streamside Zone of CSU pastures approximately 20% of the time, compared to 1% to 2% of the time for cattle in CSR or RS pastures. Consequently, cattle in CSU pastures spent less time in the Upland Zone (Fig. 3D) than cattle in either the CSR or RS pastures.

The GPS collar data showed cattle to be present in the Stream and Streamside Zones of CSU pastures less ($P < 0.05$) than observed visually. These differences are likely a result of differences in how the visual observation and GPS collar data were collected. Visual observations were conducted only during daylight hours (0600 to 1800 hours), when cattle would be more likely to visit a stream to cool themselves, while GPS collars recorded cattle position 24 h $\cdot$ d⁻¹. Additionally, cattle were fitted with GPS collars for approximately 2 wk each month while visual observations were only conducted for 2 d each month, resulting in a greater number of observation periods with GPS collars than with visual observations. The 24-h data

Figure 2. Effect of grazing management cattle occupancy of **A**, Stream, **B**, Streamside, **C**, Transition, and **D**, Upland Zones of pastures managed by continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), and rotational stocking (RS) based on Global Positioning System collar readings of cattle distribution patterns. Bars with different letters (a, b) differ ($P < 0.05$).

Figure 3. Effect of grazing management cattle occupancy of **A**, Stream, **B**, Streamside, **C**, Transition, and **D**, Upland Zones of pastures managed by continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), and rotational stocking (RS) based on visual observation of cattle distribution patterns. Bars with different letters (a, b) differ ($P < 0.05$).

Figure 4. Effect of off-stream watering sites on cattle occupancy of **A**, Stream and **B**, Streamside Zones in continuous stocking with unrestricted stream access (CSU) and continuous stocking with restricted stream access (CSR) pastures. *Grazing management (CSU, CSR) treatments differ ($P < 0.05$).

collection and longer time period allowed by the use of GPS collars make these data a more accurate representation of cattle use of riparian zones than our visual observation data.

Visual observation and GPS collar sampling periods did not coincide with the rotation of cattle into the riparian paddock in the RS pastures, resulting in an underestimation of the use of the Riparian Zone (Stream Zone+Streamside Zone) by cattle in the RS pastures. Riparian paddocks were stocked for a total of $8 \text{ d} \cdot \text{yr}^{-1}$ to $10 \text{ d} \cdot \text{yr}^{-1}$, 5.2% to 6.7% the grazing season. Therefore, actual cattle use of the riparian area in the RS pastures was 5.2% to 6.7% of the time as opposed to 1.6% or 3.8% based on GPS collar or visual observation data, respectively.

Off-Stream Water. Use of off-stream water sources to decrease cattle use of riparian areas and improve stream bank condition has had variable results, depending on environmental and site characteristics (Godwin and Miner 1996; Clark 1998; Porath et al. 2002; Agouridis et al. 2005). Providing cattle with an off-stream water source in the current study did not decrease the percentage of time spent in the Stream (Fig. 4A) or Streamside (Fig. 4B) Zone in either the CSR or CSU pastures. Access to off-stream water sources in the current study was limited to the 1-

wk periods in the months of May, July, and September of each year and for a short period in late July through early August of each year, when low stream flow restricted stream water access. If off-stream water was available for longer time periods, allowing cattle to acclimate to the presence of the water source, it is possible that an effect of off-stream water might have been detected. Differences in forage availability, between periods when off-stream water was available or not available, could also have had an impact on cattle distribution between these periods.

Effect of Cattle Distribution on Defecation and Urination Distribution

The percent of observed cattle defecations in each of the four pasture zones did not differ from the percent of observations of cattle in each zone, respectively, across the three grazing management treatments (Table 1). Similarly, percent of observed urinations in the Stream, Streamside, and Transition Zones did not differ from percent of cattle observations in these zones. However, cattle urinated in the Upland Zone (83.5%) slightly more ($P < 0.05$) than the percent of time (82.3%) they

Table 1. Differences between observed cattle defecation and urination distribution patterns and observed cattle distribution patterns within four pasture zones.

Zone	Observations, % total	Defecations, % total observed	Odds ratio	Lower CL ¹ of odds ratio	Upper CL of odds ratio	p^2
Defecation and urination distribution patterns						
Stream	2.8	2.3	1.00	0.69	1.31	NS ¹
Streamside	6.5	7.2	1.66	0.84	2.49	0.11
Transition	8.4	8.5	1.06	0.98	1.15	0.15
Upland	82.3	82.1	1.00	0.99	1.01	NS
Cattle distribution patterns						
Stream	2.8	2.4	0.84	0.43	1.25	NS
Streamside	6.5	6.2	1.44	0.52	2.35	NS
Transition	8.4	7.8	0.94	0.82	1.06	NS
Upland	82.3	83.5	1.02	1.00	1.03	0.03

¹CL, confidence limit; NS, not significant.

²Odds ratio differs from Neutrality, 1, at $P < 0.05$.

Table 2. Effect of a one-unit increase in microclimatic variable on the percentage of time cattle spend in the shade over the range of microclimatic conditions during visual observation periods.

	Pasture zone		<i>P</i>	Microclimatic range
	CSU ¹	CSR		
	-----% probability increase of cattle in shade ² (95% CL)-----			
Temp ³	19.5 (15.5–23.7)	21.9 (17.4–26.6)	NS	10–35
BGTemp	15.4 (13.5–17.3)	19.8 (17.2–22.5)	< 0.05	50–87
THI	14.5 (11.2–16.2)	15.3 (12.5–18.2)	NS	9–45
BGTHI	11.6 (10.3–13.1)	15.4 (13.6–17.3)	< 0.05	47–101
HLI	7.6 (6.8–8.5)	10.5 (9.3–11.7)	< 0.05	21–79

¹CSU, continuous stocking with unrestricted stream access; CSR, continuous stocking with restricted stream access; CL, confidence limit; and NS, not significant.

²Increase in probability of cattle in shade with each one-unit increase in microclimatic condition.

³Temp, temperature (°C); THI, temperature humidity index; BGTemp, black globe temperature; (°C); BGTHI, black globe temperature humidity index; and HLI, heat load index.

were observed in this zone. From these relationships, it can be assumed that nutrients and pathogens excreted by grazing cattle will also be distributed proportional to the percent of time spent in a given zone. Based on GPS collar data of cattle in the CSU pastures of the current study, this assumption would result in approximately 1.2% of the fecal material and urine deposited directly in the stream and an additional 10.6% of the fecal material deposited within 33 m of the stream. These results are consistent with those of Ballard and Krueger (2005), who reported that cattle defecations were proportional to the time spent in different habitats, resulting in 2% of manure being directly deposited in a stream. White et al. (2001) reported cattle distribution patterns to be highly correlated with defecation ($R^2 = 0.94$) and urination ($R^2 = 0.99$) distribution patterns for dairy cattle in an intensively managed pasture system.

Effect of Microclimate on Cattle Distribution

Shade. Beef cattle at maintenance have a thermal neutral zone between 5°C and 15°C (Hahn 1999); outside this range, free-ranging cattle may alter their behavior to regulate body temperature. As Temp, BGTemp, THI, BGTHI, and HLI

increased, across the range during observation periods (Table 2), the probability of cattle being in the shade increased ($P < 0.05$) in both CSU and CSR pastures. No effect of grazing management treatment on the probability of cattle being in the shade was detected with Temp or THI. For each one-unit increase in Temp (Fig. 5) and THI, there were 20.7% and 14.5% increases, respectively, in the probabilities of cattle in CSU and CSR being in the shade. However, a significant effect ($P < 0.05$) of grazing treatment on the probability of cattle being in the shade was detected for BGTemp, BGTHI, and HLI. In CSU pastures, the probability of cattle being in the shade increased 15.4%, 11.6%, and 7.6% for each unit increase in BGTemp, BGTHI, and HLI, respectively. In CSR pastures, the probability of cattle being in the shade increased 19.8%, 15.4%, and 10.5% for each unit increase in BGTemp, BGTHI, and HLI, respectively. The greater probability of cattle being in the shade in CSR pastures at higher BGTemp, BGTHI, and HLI than in CSU pastures is possibly related to cattle having greater access to the stream in CSU pastures. Even though cattle in the CSR pasture had stream access at the stream crossing, cattle did not appear to loiter in this area as cattle in the CSU pastures did during hot weather. Based on the AIC of each prediction determined by the logistic procedure, ambient temperature was superior to the other microclimatic variables in predicting cattle presence in shade.

Figure 5. Effect of ambient temperature on the probability of cattle in continuously stocked pastures with unrestricted or restricted stream access being in the shade.

Riparian Zone. Marlow and Pogacnik (1986) reported cattle used the riparian area of a pasture more during the warmer part of the year and the uplands more during cooler periods. In the current study, as Temp, BGTemp, THI, BGTHI, and HLI increased across the ranges of microclimatic variable occurring during the periods cattle were fitted with GPS collars (Table 3), the probability of cattle being in the riparian zone of the pasture increased ($P < 0.05$) in both CSU and CSR pastures. However, the rate of increase was greater ($P < 0.05$) in the CSU (Fig. 6A) than CSR pastures (Fig. 6B). In CSU pastures, for each one-unit increase in Temp, BGTemp, THI, BGTHI, and HLI, the probability of cattle being in the riparian zone increased 12.1%, 12.0%, 7.2%, 6.8%, and 5.5%, respectively. However, in CSR pastures, each unit increase in these microclimate variables resulted in a 5.8%, 6.4%, 3.8%, 3.0%, and 2.8% increase in the probability of being in the riparian zone, respectively. An off-stream water source did not alter the probability of cattle being in the riparian zone of CSU pastures at any Temp, BGTemp, or THI. However, there was a tendency ($P < 0.10$) for off-stream water to decrease the

Table 3. Effect of a one-unit increase in microclimatic variable on the percentage of time cattle spend in the riparian zone¹ over the range of microclimatic conditions during periods cows were fitted with Global Positioning System collars.

	Pasture zone		<i>P</i>	Microclimatic range
	CSU ²	CSR		
	% probability increase of cattle in riparian zone ³ (95% confidence limit)			
Temp ⁴	12.1 (10.0–14.2)	5.8 (3.2–8.4)	< 0.05	–1 to 35
BGTemp	12.0 (10.8–13.2)	6.4 (4.7–8.1)	< 0.05	29 to 87
THI	7.2 (6.0–8.5)	3.8 (2.3–5.3)	< 0.05	–3 to 46
BGTHI	6.8 (6.2–7.5)	3.0 (2.2–3.8)	< 0.05	24 to 107
HLI	5.5 (5.0–6.0)	2.8 (2.1–3.5)	< 0.05	6 to 84

¹Riparian zone = Stream + Streamside zones.

²CSU, continuous stocking with unrestricted stream access; CSR, continuous stocking with restricted stream access.

³Increase in probability of cattle in riparian area with each one-unit increase in microclimatic condition.

⁴Temp, temperature (°C); THI, temperature humidity index; BGTemp, black globe temperature; (°C); BGTHI, black globe temperature humidity index; and HLI, heat load index.

probability of cattle being in the riparian zone as BGTHI and HLI increased. Based on the AIC determined by the logistic procedure, ambient and black globe temperatures were superior to the other microclimatic variables or indices in

predicting cattle presence in the riparian zone. This result and the finding that ambient temperature was a superior indicator of cattle presence in the shade is contrary to other studies that found equations that took more microclimatic factors into consideration were better predictors of cattle response to heat stress (Widowski 2001; Mader et al. 2006).

MANAGEMENT IMPLICATIONS

The amount of time cattle spend in streams or riparian areas is a function of management and microclimatic factors. The use of rotational stocking systems and restricting cattle stream access to reinforced crossing areas are beneficial in reducing the percentage of time cattle spend in a pasture stream and the associated riparian area. This alteration in distribution should result in improvements in stream water quality and pasture productivity brought about by more uniform pasture utilization and nutrient distribution. The availability of an off-stream watering site may also be effective in reducing cattle impacts on surface waters, particularly during periods of greater ambient temperature. Reducing the time cattle spend in riparian areas by restricting access to reinforced crossing areas or by the use of rotational grazing systems may be particularly effective during warmer parts of the year when cattle prefer to spend more time near water. Ambient and black globe temperatures are superior to climate indices, which require measuring several microclimatic variables, in predicting the presence of grazing cattle in shade or riparian areas.

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Figure 6. Effect of ambient temperature on the probability of cattle being in the riparian zones of pastures that were continuously stocked with **A**, unrestricted or **B**, restricted stream access.

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