J. Range Manage.
56: 146-151 March 2003

An index for description of landscape use by cattle

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Abstract

Understanding the role of landscape diversity in livestock distribution patterns is an important consideration for design of effective grazing systems. The objective of this study was to develop and evaluate a Distribution Evenness Index (DEI) based on the Shannon-Wiener index to characterize cattle distribution patterns for a heterogenous landscape within a given period of time. Observations of diurnal behavior of beef cattle (*Bos taurus*) were made in grassland, wooded, and riparian habitats within a fenced landscape from March to October 2000 at a farm in north-central Alabama. The DEI was calculated based on observation records at different time intervals (15-, 30-, and 60-min) and different levels of grassland habitat subdivision (18-, 9-, and 6-zones). Comparisons of calculated DEI values were made among different habitat types, observation intervals, landscape subdivision levels, and daytime periods. Annual DEI means indicated low evenness of cattle distribution in riparian (0.517) and wooded habitats (0.606), and consistently high evenness in the grassland habitat (0.860). Although grazing activity in the grassland habitat was uneven between different daytime periods (0.565 to 0.679), when combined for the total daytime period, grazing activity in the grassland habitat had a high evenness value (0.855). Relative stability of the DEI calculated between selected spatial and temporal scales in this study indicated that the index may be useful for comparison of evenness of livestock habitat use and grazing patterns between different studies at similar spatial and temporal scales.

Key Words: beef cattle, diurnal grazing behaviors, location choice, distribution evenness, riparian areas

Resumen

Entender el papel de la diversidad del paisaje en los patrones de distribución del ganado es de considerable importancia para el diseño de sistemas de apacentamiento efectivos. El objetivo de este estudio fue desarrollar y evaluar in Índice de Uniformidad de Distribución (DEI) basado en el índice de Shannon-Weiner para caracterizar los patrones de distribución del ganado en un paisaje heterogéneo dentro de un periodo de tiempo dado. Se hicieron observaciones del comportamiento diurno del ganado para carne (*Bos taurus*) en hábitats de zacatal, boscoso y ribereño, las observaciones se realizaron de marzo a abril del 2000 dentro de un paisaje cercado en una granja de la región norte-centro de Alabama. El DEI fue calculado en base a los registros de observación a diferentes intervalos de tiempo (15, 30 y 60 min) y diferentes niveles de subdivisión del hábitat de zacatal (18, 9 y 6 zonas). Se realizaron comparaciones de los valores calculados del DEI entre diferentes tipos de hábitat, intervalos de observación, niveles de subdivisión del paisaje y periodos del día. Las medias anuales del DEI indicaron una baja uniformidad de la distribución del ganado en los habitats ribereño (0.517) y boscoso (0.606) y una uniformidad consistentemente alta en el hábitat de zacatal (0.860). Aunque la actividad de apacentamiento en el hábitat de zacatal fue desuniforme entre los diferentes periodos del día (0.565 a 0.679) cuando se combinaron para el total del periodo del día, la actividad de apacentamiento en el hábitat de zacatal tuvo un valor de uniformidad alto (0.855). La estabilidad relativa del DEI calculada entre las escalas espaciales y temporales seleccionadas en este estudio indicó que el índice puede ser útil para la comparación de la uniformidad del uso del hábitat por el ganado y los patrones de apacentamiento entre diferentes estudios en escalas espaciales y temporales similares.

Grazing distribution patterns affect optimal forage utilization, nutrient recycling, and ultimately, pasture persistence and grazing capacity. Thus, an important principle of grazing management is to maintain an even distribution of grazing animals within a grazing unit or area (Vallentine 2001). In addition, animal agricultural production practices are being increasingly scrutinized for their impact on water quality throughout the USA (Martin 1997). Therefore, livestock distribution is a fundamental concern in grazing system design. This is especially true for grazing units that include wooded riparian areas, since cattle have been reported to spend more time near shade and water sources (Blackshaw and Blackshaw 1994).

Multiple regression (Senft et al. 1983), probability distributions (Arnold and Maller 1985), and inverse Gaussian distribution function (Pickup 1994) have been used to predict or measure livestock grazing distribution patterns. A drawback to these approaches is that these models cannot be transferred from 1 site to another since relationships between distribution patterns and environmental characteristics vary from location to location (Bailey et al. 1996). The objective of this study was to develop an index based on modification of the Shannon-Wiener index (Shannon and Weaver 1949) by which evenness of the distribution patterns of cattle location choice and behaviors could be easily quantified within a heterogeneous landscape over a given period of time. Sensitivity and stability of the distribution evenness index was tested at different temporal and spatial scales.

The authors wish to thank Mr. James Glenn, Glendale Farms, Moulton, Ala. for generously allowing access to his property. We also thank Mr. Rick Zellmer, GIS Specialist, USDA-NRCS, Auburn, Ala. for assistance with map development.
Manuscript accepted: 15 Jun. 02.

Materials and Methods

Description of study site

The study was conducted between March and October 2000 at Glendale Farms, close to the town of Moulton (196.6 m, 34°29'N, 87°18'W) in the Flint Creek Watershed of north-central Alabama, USA. The average annual temperature is 13 to 16°C. Average annual precipitation is 925 to 1,400 mm with maximum in midwinter and midsummer, and minimum in autumn. Stream discharge is generally greatest in late winter and spring in response to precipitation. Precipitation is generally adequate for forage growth, however, dry periods early in summer and in autumn can reduce biomass production. Rainfall during the study period ranged from a high of 220 mm in April to a low of 0 mm in October (Fig. 1). Total rainfall for the study period was 257.3 mm lower than the previous 30-year average.

The studied landscape was fenced to about 3.3 ha in rectangle and was part of a larger grazing system that used rotational stocking. A second-order stream (Sheats Branch) flowed through the studied landscape (Fig. 2). The producer had an 80-head beef cow-calf (*Bos taurus*; Hereford) herd that was allowed yearlong access to the stream. During observation periods, stocking density of the studied landscape averaged 5 AU ha^{-1} (20 total head) during the cool season (October to April) and 4 AU ha^{-1} (17 total head) during the warm season (May to September).

Three habitat types were defined within the studied landscape as riparian (stream, streambanks, and streamside woods), grassland (open pasture area), and wooded (wooded areas along fence line and drainage way). The area ratio of different habitat types was 1 (wooded) : 1.6 (riparian): 6 (grassland). Ground cover composition was quantified in both the grassland and riparian habitats using a point sampling technique (Buckner 1985). Endophyte-infected tall fescue (*Fescuta arundinacea* L.) was the predominant vegetation cover (84%) in the grassland habitat of the studied landscape; common bermudagrass (*Cynodon dactylon* L.) contributed up to 11% of the grassland vegetation cover. Measurements indicated uniform fescue production and utilization throughout the grassland habitat (Zuo 2001). Sycamore (*Platanus occidentalis* L., 54.3%) and oak (*Quercus* sp., 19.8%) were the dominant overstory species in the 5- to 10-m wide wooded portions of the riparian habitat; riparian overstory cover averaged 48% in winter and 84% in summer. Ground cover of the riparian habitat understory was dominated by the combination of litter (41%) and bare ground (28%). The total vegetative portion of the understory ground cover averaged 21% during the study period; tall fescue comprised approximately 40% of the total understory vegetation cover.

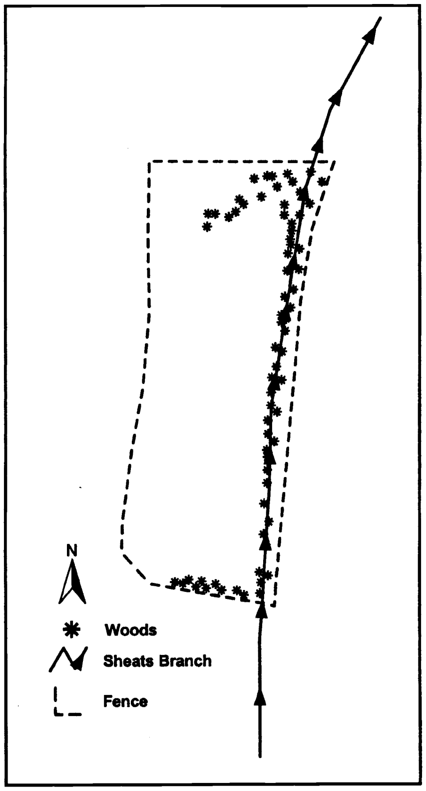

Fig. 2. Map of the studied landscape (3.3 ha), Glendale Farms, north-central Ala.

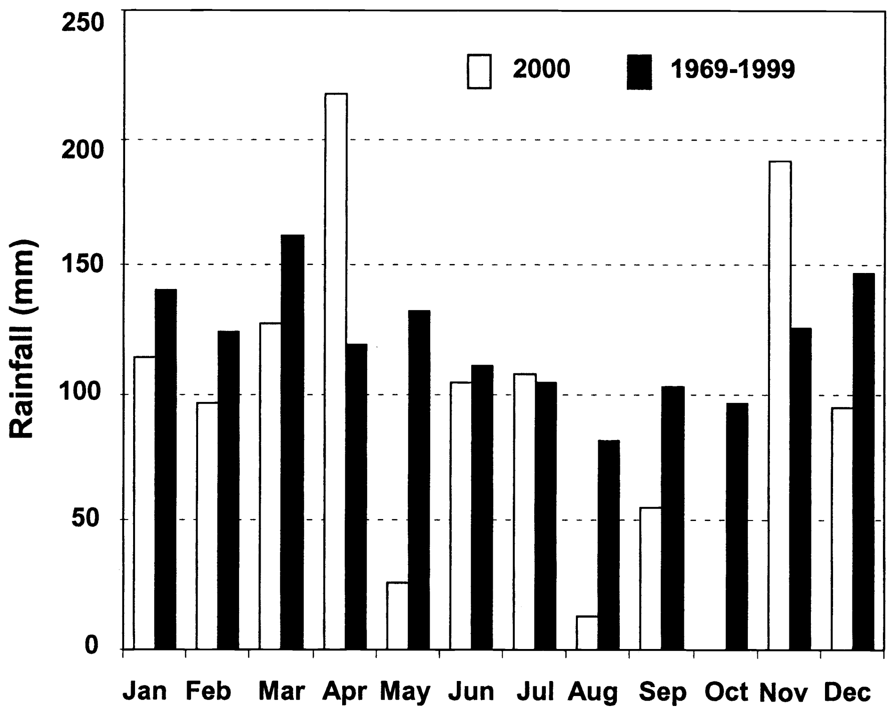

Fig. 1. Monthly rainfall during 2000 compared to the previous 30-year average, north-central Ala.

Observation of cattle behavior

Two-day diurnal observations of cattle behavior were made in March 2000; 1-day diurnal observations were made in May, July, August, and October 2000. From daybreak to dark, observations of weather conditions and cattle behavior were conducted at 15-min intervals with the assistance of binoculars from a convenient point that avoided disturbance of cattle. Data recorded during observations included: temperature, wind direction (Table 1), total number of head at each location, and activities of individual animals, such as grazing, lying, and loafing. Grazing activity represented times when cattle were harvesting and masticating forages; lying activity represented times when cattle were lying down at a given location; loafing activity represented activities other than grazing and lying, such as moving, standing, itching, and playing. The location, numbers, and behavior categories of cattle were recorded on a landscape map for each time interval during the observation periods; those maps were referred to as distribution plots. Total time was calculated as the sum of time cattle spent in the riparian habitat (including the stream), the grassland habitat, and the 2 areas of wooded habitat. Grazing time, lying time, and loafing time combined represented the total time period of the observation. The percentage of cattle participation in each activity within each habitat type was calculated. Based on the record of 15-min interval observations, 30- and 60-min-interval records were generated by deletion of 1 or 3, 15-min intervals in the calculation.

Calculation of the Distribution Evenness Index

For each distribution plot recorded at a given time interval, the total landscape area was subdivided into zones by overlaying a transparent zone-subdivision of the landscape on each distribution plot. The transparent overlay had 5 zones evenly delineated in the riparian habitat, 18 zones in the grassland habitat, and 3 zones in the 2 wooded habitats within the studied landscape. For the grassland habitat only, transparent overlays with 9- and 6-zone subdivisions were also applied separately to each distribution plot. Based on the summary record of cattle numbers and behavior categories for each zone at a given period of time, an index of cattle distribution evenness was calculated by a modification of the Shannon-Wiener index (H'). The information parameter H' was defined as:

$$H' = -\sum_{i=1}^{Z} p_i \ln p_i \qquad (1)$$

Where p_i = the proportion of total number or behavioral categories of beef cattle in the ith zone;

Z = total number of zones studied.

For zones without a record of any category of behavioral activity, 0.001 was assigned to make the calculation mathematically feasible. The statistic H' was then standardized for the number of zones involved (Z) to achieve the Distribution Evenness Index (DEI):

$$\mathrm{DEI} = H'/\ln Z = (-\sum_{i=1}^{Z} p_i \ln p_i)/\ln Z \qquad (2)$$

The Shannon-Wiener index was initially developed for human communication theory (Shannon and Weaver 1949) and has been widely applied in ecology as a measure of species diversity. Two assumptions must be satisfied to use the index for species diversity measurement: (1) individuals are randomly sampled from an ‘infinitely large’ population and (2) all species from a community are included in the sample (Kent and Coker 1992). Although the original purpose of the Shannon-Wiener index was to describe many types of human behavior, the DEI modification should be suitable to describe the distribution of cattle location choice since cattle behavior is a continuous process and the number of subdivision zones is fixed for a given area studied.

To simplify the mathematical explanation of the DEI, suppose there are only 2 zones within a grazed landscape. When the 2 probabilities of cattle choice of each zone are equal, the DEI is largest and reduces to 0 when 1 zone’s freedom of choice is gone. If there are many, rather than 2 zones, then the DEI is largest when the probabilities of the choices of each zone are as near to equal as possible during a given period of time, namely, cattle spend nearly identical time in each zone. On the other hand, if the choice of 1 zone has a probability near 1 so that all the other choices have probability near 0, the indication is that the cattle’s choices are heavily influenced toward one particular zone or cattle have little freedom of choice. In that case, the DEI does calculate to have a very small value, i.e., the distribution evenness is low.

Comparisons at different temporal and spatial levels

The Distribution Evenness Index (DEI) was calculated at different time intervals (15-, 30-, and 60-min) and different subdivision levels (18-, 9-, and 6-zone) in the grassland habitat for both total activities and categorized activities. When total activities were taken into account, the DEI represented the evenness patterns of location choice or distribution within the grassland habitat. The DEI was also calculated based on the 15-min interval data for cattle location choice in different habitat types. To describe the distribution pattern of grazing behavior in the grassland habitat during daylight, the DEI was also calculated based on the 15-min interval data for morning (before 1100 hours), midday (1100 to 1300 hours), afternoon (1300 to 1700 hours), and evening (after 1700 hour) periods.

Table 1. Predominant weather conditions for behavior observation periods, north-central Ala, March to October 2000.

Date	Sunrise	Sunset	High temp.	Low temp.	Weather conditions
	(h)	(h)	(°C)	(°C)	
9 March	0606	1749	13.3	3.3	Cloudy skies, strong wind from 0600 to 1400 hours with one and one-half hour rain beginning at 0830 hour; remaining periods were sunny
10 March	0604	1750	12.7	3.3	Sunny before 0800 hour, cloudy and windy from 0800 to 1300 hours, then light rain occurred until a thunderstorm at 1700 hours that lasted until dark
11 March	0603	1751	11.1	-1.7	Light rain occurred before 1100 hours, then cloudy skies until dark
12 March	0602	1751	11.7	-1.7	Sunny and calm
22 May	0542	1950	29.5	17.2	A 2-hour rain began at 1230 hours, remaining periods were sunny
23 May	0541	1951	30.1	17.2	Sunny
18 July	0546	1958	36.1	22.2	Hazy
19 July	0547	1958	36.1	22.2	Sunny and clear
15 August	0602	1933	36.7	20.0	Sunny
16 August	0603	1932	36.7	20.6	Sunny with occasional partly-cloudy conditions
17 October	0653	1810	23.9	12.2	Cloudy during morning periods; remaining periods were sunny
18 October	0654	1809	23.9	9.4	Cloudy during morning periods; remaining periods were sunny

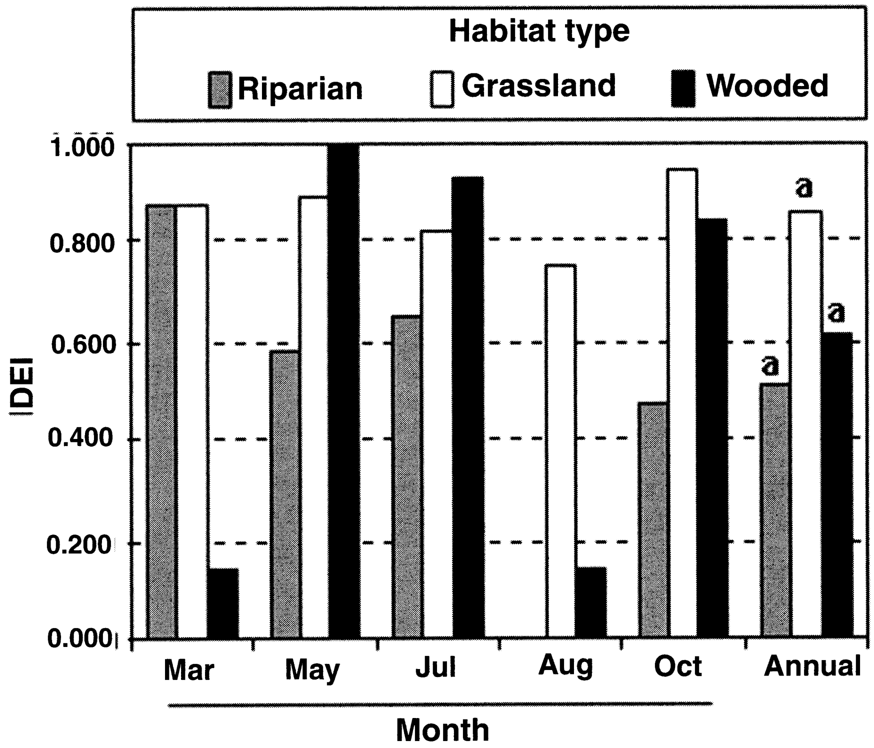

Fig. 3. Monthly and annual comparison of cattle distribution eveness indicated by the DEI (Distribution Evenness Index) for different habitat types in the studied landscape, Glendale Farms, north-central Ala. Annual means with the same letter indicate no significant difference (P < 0.05).

Because the indices themselves will be normally distributed if the Shannon-Wiener index is calculated for a number of samples (Taylor 1978), it is possible to use parametric statistics to compare sets of DEI values (Magurran 1988). To test the sensitivity of the DEI to specific cattle behaviors, the paired t-test ($P < 0.05$) was performed (PROC MEANS, SAS® version 6.12) to test differences between the DEI values for total activities and grazing activities at different time intervals in the grassland habitat and grazing activities in the grassland habitat at different zone-subdivision levels. Analysis of variance (PROC ANOVA, SAS® version 6.12) and the least significant difference ($P < 0.05$) were used to detect overall differences for total activities in different landscape habitat types, and for grazing activities in the grassland habitat at different daytime periods.

Results and Discussion

Location choice distribution

Consistently high cattle distribution evenness was indicated for the grassland habitat throughout this study. Higher distribution evenness was detected in the riparian habitat during March compared to May, July, and October (Fig. 3). However, extremely uneven use of the riparian habitat by cattle was noted in August since evenness equaled 0 at that time. The wooded habitats had very high DEI values in May, July, and October, and very low Distribution Evenness Index (DEI) values in March and August. Annual means of diurnal observations indicated that evenness of cattle distribution was low in riparian and wooded habitats, and high in the grassland habitat. About 90% of total activities that occurred in the grassland habitat were grazing and about 75% of the total activities that occurred in wooded or riparian habitats were lying and loafing (Zuo 2001). Thus grazing activities caused consistently higher distribution evenness in the grassland habitat while unstable evenness patterns in riparian or wooded habitats were most closely related to seasonal effects on loafing and lying activities.

Effects of temporal and spatial levels

Higher evenness of cattle distribution in the grassland habitat was indicated by the DEI calculated using 15-min interval observation records for both location choice and grazing activities during the cool-season versus the warm-season (Table 2). The most uneven distribution occurred in August, the warmest period during this study, when cattle spent the majority of diurnal time lying or loafing in wooded habitats and their foraging activities occurred mainly in shaded areas of the grassland habitat close to wooded or shaded riparian habitats. The similar evenness pattern of total activities and grazing activities demonstrated the major influence of grazing activities on cattle location choice in the grassland habitat (Table 2). On the other hand, this similarity further indicated that cattle spent the majority of time in the grassland habitat for grazing activities.

No significant difference was detected between the DEI values calculated using 30-min interval records and those based on 15-min interval observation records (Table 2). However, the DEI values calculated using 60-min interval records were

Table 2. Comparison of DEI (Distribution Evenness Index) values for cattle location choice for all activities and grazing activity in the grassland habitat at different time-interval levels, Glendale Farms, north-central Alabama 2000.

	All activities			Grazing activity		
	15-min	30-min	60-min	15-min	30-min	60-min
March[†]	0.883	0.890	0.865	0.868	0.873	0.846
May	0.896	0.820	0.730	0.903	0.840	0.720
July	0.822	0.820	0.750	0.823	0.830	0.730
August	0.756	0.780	0.680	0.749	0.780	0.690
October	0.944	0.930	0.840	0.934	0.930	0.840
	Paired t-test					
	15-min vs. 30-min	15-min vs 60-min	30-min vs. 60-min	15-min vs. 30-min	15-min vs. 60-min	30-min vs. 60-min
Difference (probability)	0.012 (0.5153)	0.087 (0.0225)*	0.075 (0.0050)*	0.005 (0.7745)	0.090 (0.0278)*	0.085 (0.0054)*

[†]October through April = cool season; May through September = warm season.
*Indicates significant difference at $P < 0.05$.

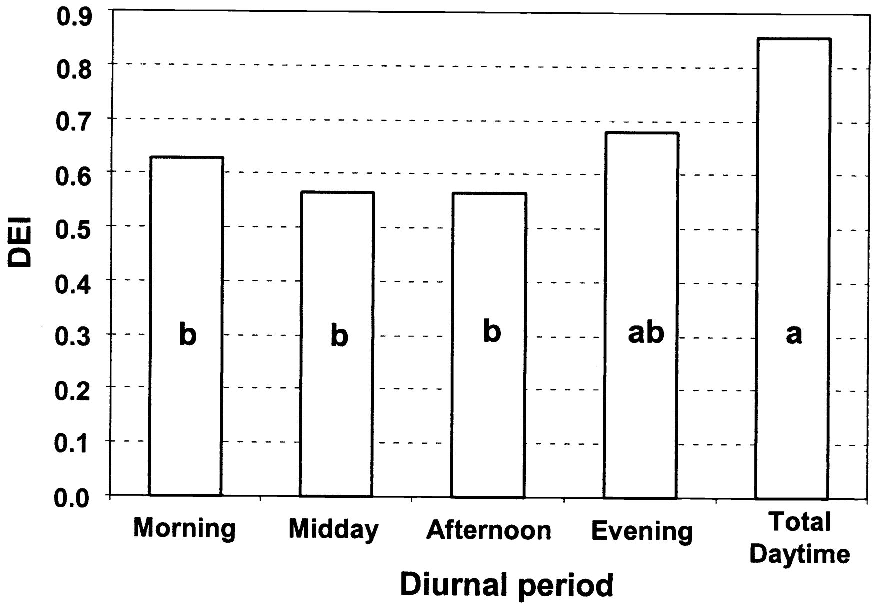

Fig. 4. Grazing distribution evenness in the grassland habitat indicated by the mean DEI (Distribution Evenness Index) for different diurnal periods, March to October 2000, Glendale Farms, north-central Ala. Means with different letters indicate a significant difference (P < 0.05).

consistently and significantly lower than the DEI values based on 15-min or 30-min interval records. This decrease indicated that information about actual cattle distribution patterns in this study could have been lost if the observation interval had been greater than 30 min.

Relative stability of the DEI was detected at various levels of grassland habitat subdivision for both 15- and 30-min interval records, especially during the cool-season (Table 3). Higher DEI values were obtained during the warm season when the 6- or 9-zone subdivision was used for the grassland habitat; an exception was the 6-zone subdivision in August. It appeared that subdivision with a larger zone size inflated the unevenness of cattle distribution when the true value of DEI was actually relatively low. On the other hand, the subdivision of a given habitat area itself should not be so small as to impact animal aggregation behavior, namely, each zone should be able to hold all animals together with enough inter-animal distance, about 78.5 m^2 $head^{-1}$ (Phillips 1993). For example, the 18-zone grassland habitat subdivision in this study allowed approximately 80 m^2 $head^{-1}$ when all cattle were in 1 zone, even during the cool-season when a higher stocking density was employed.

Table 3. Comparison of DEI (Distribution Evenness Index) values for 15- and 30-min interval records at different levels of grassland habitat subdivision, Glendale Farms, north-central Ala., 2000.

	15-min interval records			30-min interval records		
	18-zone	9-zone	6-zone	18-zone	9-zone	6-zone
March†	0.868	0.865	0.881	0.875	0.886	0.900
May	0.903	0.968	0.991	0.843	0.899	0.949
July	0.823	0.880	0.892	0.839	0.899	0.878
August	0.749	0.769	0.644	0.788	0.818	0.719
October	0.934	0.965	0.985	0.930	0.961	0.987
			Paired t-test			
	18-zone vs. 9-zone	18-zone vs 6-zone	9-zone vs. 6-zone	18-zone vs. 9-zone	18-zone vs. 6-zone	9-zone vs. 6-zone
Difference	−0.034	−0.023	−0.011	−0.038	−0.032	0.006
(probability)	(0.0515)	(0.5365)	(0.7250)	(0.0144)*	(0.3317)	(0.8283)

†October through April = cool season; May through September = warm season.

Temporal distribution of grazing activities

Consistently high evenness of diurnal grazing patterns in the grassland habitat was indicated by the DEI based on total daytime observations, although uneven grazing patterns were detected for different daytime periods from March to October (Fig. 4). This result suggested that cattle could choose different zones at different times with small overlap between them, or their patch preference at different periods of daytime was complementary across the total daytime period. This temporal distribution pattern of cattle grazing activities supports the suggestion made by Senft et al. (1987) that observed distribution patterns are the cumulative effects of diet selection and feeding station behaviors. It also supports the conclusion made by Bailey (1995) that no patch preferences will be measured in a homogeneous area if data are pooled within a day, and time spent in patches is not consistent throughout the day.

Advantages and drawbacks

An important criticism of grazing behavior studies has been that there is no standardized technique of observation (Bailey et al. 1996), thus making comparison of animal behavioral patterns difficult between different studies. The use of the DEI in this study demonstrated that the index has relative stability for observation intervals less than 30-min and different grassland habitat subdivision levels. We hypothesize that the relevant sensitivity or stability range of DEI could be acquired for larger landscape areas based on livestock activities pooled across several weeks. This information could then be used to describe overall grazing patterns in the landscape as well as evenness of forage utilization. In these circumstances, Global Positioning System (GPS) technology could be used to obtain animal landscape positions at 5-min intervals (Turner et al. 2000). Thus, additional information about livestock distribution could be obtained for larger landscapes through combination of the DEI with GPS technology.

The DEI appears to be a relatively simple and direct method of obtaining information about uniformity of cattle distribution in heterogeneous landscapes. The advantages of temporal and spatial stability should facilitate use of the DEI for rapid evaluation of the effects of certain management practices on cattle distribution patterns for the same pasture, or comparison between different studies with similar spatial and temporal scales.

Summary and Conclusions

Uniformity of cattle distribution patterns in a grazed landscape was described by a Distribution Evenness Index (DEI) based on modification of the Shannon-Wiener index. The DEI also provided general information about evenness of cattle habitat use for various behaviors within the heterogeneous landscape studied. When the DEI was calculated based on observations at a given time interval, cattle distribution evenness could be described for any behavior type or temporal period. This study, conducted at a small spatial scale (3–4 ha), indicated that observations should be made at time intervals of 30-min or less since behavioral information was lost when longer intervals were used. However, relative stability of the DEI calculated between selected spatial and temporal scales in this study indicated that comparison of the evenness of livestock habitat use and grazing patterns between different studies at similar spatial and temporal scales is possible and should be explored through further research.

Literature Cited

Arnold, G.W. and R.A. Maller. 1985. An analysis of factors influencing spatial distribution in flocks of grazing sheep. Appl. Anim. Behav. Sci. 14:173–189.

Bailey, D. W. 1995. Daily selection of feeding areas by cattle in homogeneous and heterogeneous environments. Appl. Anim. Behav. Sci. 45:183–200.

Bailey, D.W., J.E. Gross, E.A. Laca, L.R. Rittenhouse, M.B. Coughenour, D.M. Swift, and P.L. Sims. 1996. Mechanisms that result in large herbivore grazing distribution patterns. J. Range. Manage. 49:386–400.

Blackshaw, J.K. and A.W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behavior: A review. Aust. J. Exp. Agr. 34:285–295.

Buckner, D.L. 1985. Point-intercept sampling in revegetation studies: Maximizing objectivity and repeatability. p.110–113. *In:* Proc. 2nd Annu. Meeting. Bridging the gap between science, regulation, and the surface mining operation. Amer. Soc. Surface Mining and Reclamation, Princeton, W.Virg.

Kent, M. and P. Coker. 1992. Vegetation description and analysis: A practical approach. CRC Press, Inc., Boca Raton, Fla.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.

Martin, J.H., Jr. 1997. The Clean Water Act and animal agriculture. J. Environ. Qual. 26: 1198–1203.

Pickup, G. 1994. Modeling patterns of defoliation by grazing animals in rangelands. J. Appl. Ecol. 31:231–246.

Phillips, C.J.C. 1993. Cattle behaviour. Farming Press, Ipswich, U.K.

Senft, R.L., L.R. Rittenhouse, and R.G. Woodmansee. 1983. The use of regression equations to predict spatial patterns of cattle behavior. J. Range Manage. 36:553–557.

Senft, R.L., M.B. Coughenour, D.W. Bailey, L.R. Rittenhouse, O.E. Sala, and D.M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioSci. 37:789–799.

Shannon, C.E. and W. Weaver. 1949. The mathematical theory of communication. Univ. of Ill, Urbana, Ill.

Taylor, L. R. 1978. Bates, Williams, Hutchinson – a variety of diversities. p. 1–18. *In:* Mound, L. A. and N. Warloff (ed.) Diversity of insect faunas: 9th Symposium of the Royal Entomological Society. Blackwell, Oxford.

Turner, L.W., M.C. Udal, B.T. Larson, and S.A. Shearer. 2000. Monitoring cattle behavior and pasture use with GPS and GIS. Can. J. Anim. Sci. 80:405–413.

Vallentine, J.F. 2001. Grazing Management (second edition). Academic Press, San Diego, Calif.

Zuo, H. 2001. Cattle behavior and impacts on streamwater quality. Ph.D. Diss. Auburn Univ., Auburn, Ala.