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The Landscape Ecology of Pastoral Herding: Spatial Analysis of Land Use and Livestock Production in East Africa

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Understanding landscape-scale patterns of herding is critical in identifying and assessing the impacts of pastoral grazing. Here, a general model of herding is developed based on the Sukuma agropastoral system in the Rukwa Valley, Tanzania. Using this conceptual framework, the factors affecting the maximum distances herds travel from home and the distribution of grazing around pastoral settlements are examined. The distribution of dry season water structured the landscape-scale distribution of grazing throughout the year, not just during the dry season. Water availability strongly affected the distances herds ranged from home in the dry season and the distribution of grazing around pastoral settlements throughout the year. Associations between cattle productivity and herding practices were also examined. The effects of traveling further from home, keeping cattle in large herds, and using/living in areas of high settlement densities were examined on the following measures of productivity: intake rates, foraging behavior, milk yields, and body conditions. Cattle from larger herds were observed to walk more while actively foraging and engage in more walking bouts (taking ten steps without taking a bite). The increased walking of large herds may explain why they range farther from home and highlight the importance and ubiquity of herd splitting among pastoralists. However, herd size effects were not apparent in intake rates or milk yields. Milk yields were negatively affected by traveling farther from home. These data demonstrate substantial variability within herding populations and show interesting similarities with herding systems in substantially more arid areas.

KEY WORDS: pastoralism; GIS; Sukuma; Tanzania.

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INTRODUCTION AND BACKGROUND

Identifying and characterizing the ecological impacts of pastoral production are contentious topics in both the anthropological and biological literature (Brown, 1971; du Toit and Cumming, 1999; Ellis and Swift, 1988; Enghoff, 1990; Homewood, 1987, 1995; Homewood and Rodgers, 1984, 1991; Lamprey, 1983; Lane, 1996; Lindsay, 1989; Little, 1996; McCabe, 1990b; Nyerges, 1980; Prins, 1992; Sinclair and Fryxell, 1985; Ward *et al.*, 1998). A key element of these debates is the spatial dimension of impacts and pastoral herding, i.e., where herding takes place and what factors affect this distribution. Anthropologists have long recognized the importance of mobility and the spatial aspects of pastoral land use (reviewed in Dyson-Hudson and Dyson-Hudson, 1980, and McCabe, 1994). Like other grazing systems, pastoral herding and the decisions that affect it occur across a hierarchy of spatial and temporal scales (see Bailey *et al.*, 1996, Coughenour, 1991, and Senft *et al.*, 1987, for general reviews of grazing systems). These range from continental-scale expansion and migration (Collett, 1989; Johnson, 1989; Marshall, 1990; Waller, 1985), to nomadic movements (Dyson-Hudson & Dyson-Hudson, 1980; McCabe, 1985, 1994), more regular seasonal transhumance (Evans-Pritchard, 1940; Western, 1975; Nyerges, 1982; Århem, 1985; Homewood and Rodgers, 1991), daily herding (Coppock *et al.*, 1986a, 1986b; Homewood and Rodgers, 1991; Nyerges, 1982) down to sub-daily, landscape- or patch-scale movements (de Boer and Prins, 1989).

At each of these levels of organization, a variety of factors influence the distribution of pastoralists and their livestock. Understanding the factors affecting the distribution of grazing (and their relative importance) at any of these scales may help to recognize heterogeneity in resource use (e.g., Coppolillo, in press), point to areas where resource conflicts are likely or particularly acute (e.g., Fox *et al.*, 1996), or provide a deeper understanding of the long-term factors shaping current landscape structure and ecosystem function (e.g., Turner, 1998a, 1998b).

Here I present a conceptual model of daily herding and describe a method for using a Geographic Information System (GIS) to evaluate the factors affecting daily herding patterns and their resultant effects on livestock productivity. Using this conceptual framework, I examine the factors affecting households' daily patterns of pastoral grazing and how variation in these patterns affects herd productivity among Sukuma agropastoralists living in western Tanzania. In the first analysis I examine the effects of labor availability, cultivation practices, herd size, water availability, and settlement density on the distances herds traveled from home and the distribution of grazing around herding households. I then examine different land use practices and their effects on alternative measures of herd productivity. Specifically, I analyze the effects of distances traveled from home, settlement density, and herd size on foraging behavior (intake and stepping rates), milk yields, and animals' body condition.

The perspective of this study differs from previous research in two ways. First, rather than characterizing the overall Sukuma herding system, I focus on variability within the system. Many (but not all) of the studies mentioned above analyze and describe herding at the population level. While population-level approaches have undoubtedly proven fruitful, providing the foundation for our current understanding of pastoral systems, one limitation is that they do not examine variability among individual herding units. Examination of individual-level variability in land use practices can provide a deeper understanding of the factors affecting herding decisions (Dyson-Hudson and Dyson-Hudson, 1969; Borgerhoff Mulder & Sellen, 1994; McCabe, 1994; Sieff, 1997) as it has for other aspects of pastoral systems (e.g., Borgerhoff Mulder, 1998; Mace, 1993a, 1993b; Roth, 1996; Sellen, 1999). Second, I examine daily herding through the lens of landscape ecology. By focusing on the relationships between landscape pattern and ecological processes (Urban *et al.*, 1987; Forman, 1995), landscape ecology offers a useful framework for examining the factors affecting daily herding and how they may translate into overall landscape patterns (Coppolillo, in press; McIntyre and Hobbs, 1999). This perspective and its focus on the relationships between herding and specific landscape features (e.g., water and other pastoral settlements) builds on previous studies of herding (Homewood and Rodgers, 1991; Nyerges, 1982; Western, 1975), but is also a departure from others, which focus on economic (e.g., Sandford, 1982; Schneider, 1957), social (Conant, 1982; McCabe, 1990b), and political (Johnson, 1989) determinants of land use. The approach presented here serves two purposes. First, it provides a quantitative method for analyzing and predicting the spatial distribution of pastoral grazing. This is important as it provides a quantitative foundation for ecological monitoring, a critical element of natural resource management and conservation projects aimed at engaging local people (Kremen *et al.*, 1994). Second, it evaluates the importance of factors affecting the distribution of grazing intensity. This may be important in understanding the household and landscape factors underlying observed distributions of grazing intensity.

The Rukwa Valley and the Sukuma Agropastoral System

This study was undertaken in the Rukwa Valley, which is the southern portion of the Great Rift Valley as it passes through western Tanzania

(Fig. 1). The topography is mostly flat with some rolling hills reaching elevations around 960 m. Annual precipitation in the Rukwa Valley is 600–900 mm and is generally concentrated in a single rainy season lasting from early December until early April. Vegetation is a mixture of seasonally flooded grasslands dominated by *Echinochloa pyramidalis*, *Themeda triandra*, and *Sporobolus pyramidalis*, and Miombo woodland, dominated by *Brachystegia*, *Julbernardia* and *Acacia* spp. Soils are a mixture of well-drained sandy soils and clayey poorly-drained "black cotton" soils. The Rukwa Valley is also an area of high conservation value. Home to Katavi National Park, Rukwa Game Reserve (KNP and RGR, respectively, Fig. 1), and four contiguous Game Controlled Areas, the Valley supports dense aggregations of large herbivores including buffalo, hippopotamus, elephant, giraffe, and a full suite of plains game and carnivores.

During the last 20 years the Rukwa Valley has experienced Tanzania's highest growth rate outside of the capital city (5.7% per annum in Mpanda District). Fueled largely by immigration, human population growth has been accompanied by fivefold increases in cattle numbers and changing

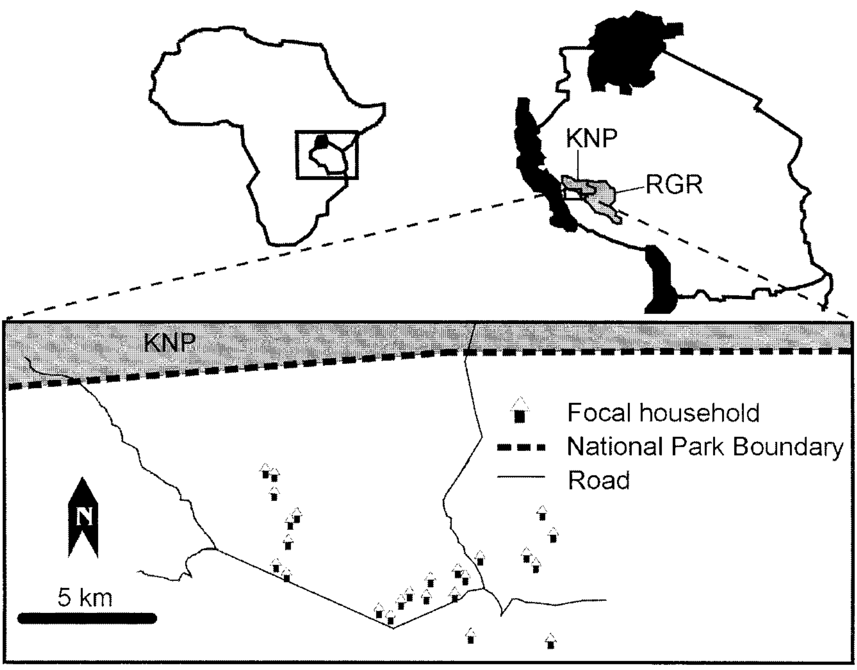

Fig. 1. The location of the study area, Katavi National Park (KNP), Rukwa Game Reserve (RGR), and the 24 households included in the study.

land uses (Tanzania, 1988, 1989, 1992, 1994). This study was initiated to understand the current land use system and the constraints that herding households face in order to inform livestock and natural resource management in the Rukwa Valley and elsewhere.

Research took place among Sukuma agropastoralists, a Bantu-speaking ethnic group who have settled in the Rukwa Valley during the last 25 years. Originally from Shinyanga, Mwanza, and Tabora Regions (to the north of Rukwa Region), the Sukuma are Tanzania's largest ethnic group and are now numerous in every region (Galaty, 1988). The human and livestock population growth in Rukwa Region and the Rukwa Valley is largely due to Sukuma immigrants; in fact, in many villages Sukuma now outnumber the original inhabitants, the Pimbwe and Rungwe (M. Ndegewilaya, pers. comm.). Shinyanga, Mwanza, and Tabora are widely considered severely degraded (Brandström *et al.*, 1979; Brandström, 1985; Maganga, 1987) and many immigrants cite environmental degradation and a lack of grazing land as factors driving them from their traditional homeland (Coppolillo and Borgerhoff Mulder, unpublished data, and see Charnley, 1994, 1997).

The Sukuma of the Rukwa Valley are strongly agropastoral, keeping mostly cattle with a few goats and sheep. All households grow maize using ox-drawn plows; poor households without steers or a plow enlist the help of wealthier relatives or pay a neighbor to prepare their fields. Some households also cultivate millet (for subsistence), and rice (for subsistence and cash). Cassava, finger millet, and a variety of small vegetable crops are also cultivated by hand. During the wet season, cattle are herded in fallow fields and undisturbed areas surrounding Sukuma settlements; harvested stubble fields are also used during the dry season. Livestock in the Rukwa Valley are only herded during the day, and all animals are enclosed at night. This is because hyenas are common and lions occasionally enter the study area from Katavi National Park, so animals left to graze at night would almost certainly be preyed upon.

As a result of "villagization" in the late 1970s, settlements in the Rukwa Valley are nucleated around a central village farm (though these are no longer communally run, see Kikula, 1997). For the most part, the central villages are occupied by Pimbwe and Rungwe, the original inhabitants of the Rukwa Valley, and Sukuma immigrants live in more dispersed satellite settlements surrounding villages. This is in part because of their recent arrival, but also because livestock conflicts are more common in densely settled areas, so most herds are kept outside of village centers. By living on the margins of existing villages, Sukuma are also able to cultivate larger areas and keep more land in fallow (for soil recovery and grazing), while still having access to the village for goods and services and social reasons. Within the satellite areas, the location of Sukuma settlements is primarily driven by the availability of arable land, forcing some households to settle as far as four kilometers from water.

Land tenure is relatively flexible in the Rukwa Valley. Land within village boundaries is titled on 33 year leases, but as mentioned above, most Sukuma live outside these areas. Here, prospective settlers must be granted permission to settle, a decision based largely on whether surrounding neighbors consider an area to have sufficient land for cultivation; if there is too little, the expectation is that land conflicts will be more likely to arise, so permission is effectively denied by discouraging immigrants from settling. Sukuma report that in theory, cattle can be herded anywhere not currently cultivated or recently harvested. In practice however, it is rare for anyone from more than a few kilometers away to use areas near others' settlements. Most households keep all of their cattle at the same settlement where they cultivate, but a few of the wealthiest herd owners (with >250–300 cattle) keep cattle at distant settlements under the supervision of older sons. Some movements of animals do occur between home and distant settlements, but these generally involve fewer than 10% of animals and are not strongly seasonal, so they cannot be accurately characterized as transhumance.

Water is managed in a more structured manner than grazing land. Recall that the topography of the Rukwa Valley is relatively flat; thus during the wet season (December–April) water is available virtually everywhere in shallow pools and flooded grasslands, so herding is not constrained by water availability. During the dry season herders dig shallow "scratch" wells to reach groundwater in dry river beds, or deeper wells where water must be hauled up using a bucket and a rope. Access to both kinds of wells is restricted to the herd owner who dug the well. Herds belonging to close kin (fathers' and sons' herds or brothers' herds) sometimes share wells, but this is not always the case. There is also one natural spring in the study area which is diverted to a pipe (for people) and a trough for livestock. All herds have access to the spring provided cattle are kept away from the area around the pipe.

A Conceptual Model of Daily Grazing

In this section I present a conceptual model of grazing based on the Sukuma agropastoral system described above. The model focuses on daily patterns of pastoral grazing. I use the term "grazing" broadly, to include herbivory and its associated ecological processes like mechanical disturbances from trampling and nutrient transfers from dung and urine deposition. Two primary characteristics of daily grazing patterns are the herding radius and the relative distribution of grazing within it. These two characteristics describe the pattern of grazing around a single pastoral settlement and, by extension, the landscape-scale distribution of grazing in areas with multiple settlements.

Herding radius is defined as the maximum distance a herd travels from home during any single day. Although strongly correlated, herding radius is not simply half the total distance traveled; if a herd takes a circuitous route but never strays farther than 1 km from home, the herding radius is 1 km regardless of how far it traveled in total. While the overall distance that a herd travels (both horizontally and vertically) is undeniably important in terms of livestock energetics and productivity (Coppock *et al.*, 1986a; Coppock *et al.*, 1986b; Homewood and Rodgers, 1991; but see Western and Finch, 1986), this study focuses on herding radius because it circumscribes the area used by each herd. This, in turn, affects the degree of overlap in grazing by herds from different pastoral settlements and drives landscape-scale heterogeneity in grazing intensity.

A variety of household-level factors may influence herding radius. First, the need to water animals may draw herds farther from home than would be necessary based solely on grazing resources. Alternatively, being close to water may eliminate travel time to and from watering and allow a herd to travel farther from home. Thus, positive and negative relationships between herding radius and households' distance to water are possible. Second, herds from households surrounded by larger numbers of other pastoral settlements may be forced to travel farther to find sufficient grazing resources, so settlement densities may also affect herding radius. Third, households' labor pools and cultivation practices may affect herding radius by constraining the amount of time allocated to herding and therefore, the distance herds are able to travel from home. The effects of labor may depend not just on the number of people in the household, but also on the demand for their labor. In this case an interaction between labor and cultivation would affect the amount of time allocated to herding. Looking only at cultivation, herds from households with larger areas planted may be forced to travel further for grazing resources (particularly during the growing season when grazing in harvested fields is not possible). Finally, Sukuma herders also report that large herds move more quickly through patches and it is more difficult to get a large herd to settle down in a single area for grazing. Thus, the size of a household's herd may affect their herding radius by forcing the herder go farther to find sufficiently large grazing patches.

The herding radius circumscribes the area in which grazing takes place, but additional information is necessary for characterizing the distribution of grazing within its bounds. Grazing may be spread evenly within the herding radius, concentrated around home or at the edges of the herding radius, or skewed toward or away from particular landscape features. Obviously, the choice of locally optimal vegetation communities will affect this distribution in site-specific ways. More generally however, the distributions of water and other cattle-keeping settlements are likely to affect the directions herds travel from home and consequently, the landscape-scale distribution of grazing. The distribution of grazing can be skewed toward or away from water points and other settlements. The ecological significance of these shifts in grazing may depend on whether they are consistent throughout the year or occur during certain seasons. For example, grazing pressure around pastoral settlements may be homogenous when viewed over an entire year, but the timing of grazing may differ for areas in different directions relative to water. Since timing of grazing may be as important as the overall stocking rate (Westoby *et al.*, 1989; Walker, 1993), the distribution of water is likely to affect the types and distribution of impacts.

The final component of the model concerns livestock productivity. Of the household-level factors listed above, I examine the effects of herd size and settlement density on four measures of productivity. I also ask whether traveling farther (i.e., increasing herding radius) affects cattle productivity. Productivity can be assessed using a variety of measures which vary in their degree of aggregation. Intake rates and foraging behavior provide immediate measures of productivity, while milk yields and body condition give an aggregate picture of productivity on weekly to monthly time scales.

The conceptual model developed above provides a framework for examining how household- and landscape-level factors shape the distribution of grazing in pastoral and agropastoral areas. Below, I describe the data collected and analytical procedures used to evaluate the factors affecting herding practices and the resultant distribution of grazing.

DATA COLLECTION

I constructed a sample of 24 Sukuma households spread throughout the study area (Fig. 1) and stratified to capture a range of herd sizes (as a measure of wealth). "Household" is defined here as an individual herding unit (similar to Dahl & Hjort, 1976). In cases where families cultivate separately but herd their animals together I have treated them as a single household.

To link herding practices to household economic conditions, I conducted demographic surveys in all 24 households. Surveys covered the number of people living in the household, their land and livestock holdings and cultivation practices. Based on these data I calculated three related measures of labor stress in each household. I defined "total labor" as the number of individuals in a household over the age of 6. This age was chosen as the cutoff because it is around six that children are able to start herding and weeding, and because it is consistent with other studies examining labor in pastoral societies (Roberts, 1996; Sieff, 1997). Despite the widely held view that herding is a purely male activity, females did herd in this and other studies (Fratkin, 1991; Sieff, 1997). Also, during the wet season everyone in the household contributes to weeding crops, and it is only after each day's weeding that herding can begin. Therefore, the total number of people in the household, not just the males, is the relevant measure of labor as it relates to herding. "Labor demand" is defined as total labor in the household divided by the total area cultivated by the household. The final measure was simply the total area cultivated by the household (all crops were weighted equally).

To quantify spatial patterns of pastoral land use I recorded the movements of cattle herds from the 24 focal households on 73 full-day herd follows (similar to Coppock *et al.*, 1986a, 1986b; Homewood and Rodgers, 1991; Nyerges, 1982). I followed the primary (adult) cattle herd from the time they left their enclosure in the morning until they returned in the evening. Like other pastoral groups, Sukuma herd their animals separately based on age, species, and sometimes reproductive status (e.g., see Coppock *et al.*, 1986a; Homewood & Rodgers, 1991; McCabe, 1985, 1990a; Nyerges, 1982; Sieff, 1997; Turner, 1999). Because the primary herds constitute the majority of livestock biomass and because calves, goats, and sheep are often left unherded, I followed only primary cattle herds. I followed each household's herd during the dry season (Sep.–Dec., 1995), the early part of the wet season (Jan.–early Mar., 1996) and the late part of the wet season (late Mar.–May, 1996). During each herd follow, I recorded herd locations at least every hour (more often when herds were moving quickly or changing directions frequently) using a hand-held global positioning system (GPS). I refer to these data below as "route locations."[2]

Five times per hour, I observed a randomly chosen animal's behavior during a three-minute focal observation. During each observation the focal animal's bites, steps, and chews were recorded continuously. At the end of the three minutes the mean bite size was visually estimated on a scale from 1 to 5, so that an overall intake rate (bites * bite-size) over three minutes could be calculated. Through the course of the study, 2,146 observa-

[2]The GPS data were not spatially corrected since the error introduced (20–50 m) is smaller than the spread of a typical herd and not significant relative to the distances covered during a day's herding.

tions were recorded yielding over 268 hours of observation time. Behavioral records for the entire study are plotted in Fig. 2.

These data, referred to hereafter as "behavioral records," serve two purposes. First, spatially referencing behavioral records (see Data Analysis) makes it possible to analyze the distribution of grazing around pastoral settlements and evaluate the factors affecting this distribution. Second, intake rates and foraging behavior provide immediate measures of energy intake (and thus resultant livestock productivity) for herds subjected to different herding practices and for discrete points on the landscape.

Every 20 min I scanned the entire herd (or the portion of the herd that was visible) and recorded each individual's behavior as feeding, walking, standing, ruminating, lying, or drinking. As in other pastoral studies (Nyerges, 1982) these "scan samples" provide a quantitative measure of the entire herd's activity, as opposed to the behavioral records, which provided more detailed data on a single individual's behavior (Altmann, 1974). During the study, the behavior of 57,532 individuals was recorded in 1,341 scan samples.

The locations of all cattle-keeping households in the study area (N = 150) were recorded using the GPS. These data were used to calculate

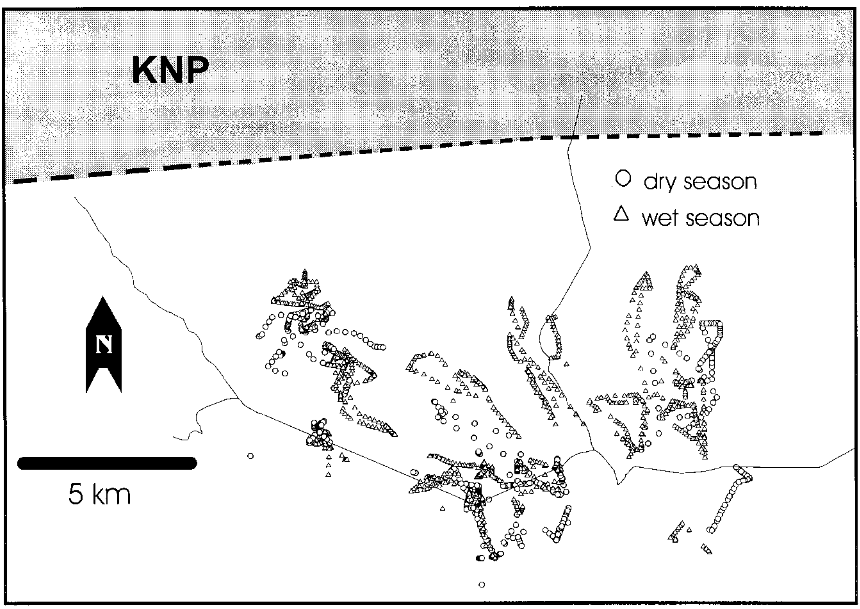

Fig. 2. The locations of all behavioral records. Legend as in Fig. 1.

settlement densities (see Data Analysis, below). As with the focal sample, households were identified based on cattle herding units, rather than cultivation or marriage units.

I used three measures of cattle productivity. First, I observed individual animals foraging behavior and calculated intake rates (described above) to provide an immediate (least aggregated) measure of productivity. The importance of walking for pastoral animals' energetics and productivity has been demonstrated elsewhere (Coppock *et al.*, 1986a, b; Homewood and Rodgers, 1991; but see Western and Finch, 1986). To monitor walking (and associated energetic costs), I counted the total number of steps taken by the animal and the number of "walking bouts," defined as ten steps taken without taking a bite. A second, more aggregated measure of productivity is milk yield, which reflects an animal's diet over the last few days to a week. Yields were measured from 532 animals (in the wet seasons only) by weighing the milk from each lactating female before it was placed into a common vessel (similar to Homewood and Rodgers, 1991). Note that this records the amount taken for human consumption, not the total produced. Finally, I used body condition as the most aggregated measure of herd productivity. Body conditions of 1,725 animals were scored on a nine-point scale developed specifically for zebu cattle (Nicholson and Butterworth, 1986). The scale quantifies animals' body condition based on the visibility of an individual's ribs and vertebrae, and muscle mass. Reference cards with photographs of animals exemplifying each condition score were used to avoid seasonal and inter-herd biases. Condition scores are tightly correlated with animals' overall weight and reflect the animal's diet and nutrition over the last few weeks or months (Nicholson and Butterworth, 1986). For each herd I scored the body condition of 30 individuals. For herds smaller than 30, I scored the entire herd. Lactating females' body condition was recorded during milking. Preliminary data collection showed that herding practices were consistent over one month intervals, so a single day's herding is generally representative of the recent past, validating its association with aggregated measures of productivity.

DATA ANALYSIS

I plotted each behavioral record spatially by interpolating between the previous and subsequent route locations. This assumes that herds move at a constant pace and in a straight line between each route location, both reasonable assumptions given the frequency of records and the fact that when a herd's pattern of movement changed additional route locations were recorded. This allowed me to spatially reference each behavioral record.

All behavioral records were then entered into a Geographic Information System (ArcInfo, 1997, henceforth GIS) as text files. Each behavioral record was referenced according to its distance and compass bearing from home. These data make it possible to quantitatively examine the total distance traveled, the herding radius, and the spatial distribution of herding records (as a measure of grazing intensity) around each settlement.

The calculation described above characterizes herds' locations and movements relative to grid north. A more relevant expression of direction for testing hypotheses relating to water distributions may be "toward or away" from water. In order to compare the movements of each household's herd relative to its home and dry season water source, I created a standardized grid plotting all behavioral records relative to these two points. Figure 3 is a schematic diagram of this process. Conceptually, this process is analogous to plotting each herd's movements on a small map and then aligning the maps for all herds so that water falls due "north" of each settlement (see the lower panel of Fig. 3). This effectively standardized every herd's movements allowing them to be compared and analyzed collectively.

To achieve this conversion quantitatively, I used the GIS to calculate the direction from each household to its dry season water source. The directions of all behavioral records associated with that household's herd were then adjusted relative to this value. Thus, the value given to each behavioral record's direction is the difference between the bearing from the record itself to home and the bearing from that household's dry season water source to home. All behavioral records were then given coordinates that expressed location relative to home (which was at the origin on an imaginary grid) and the dry season water source (lying due "north" of the homestead on the imaginary grid).

I statistically analyzed the spatial pattern of grazing in relation to water by comparing the numerical distribution of directions for behavioral records (expressed in degrees from 0–180) with a uniform distribution using a Kolmogorov Smirnov Z statistic (I performed all statistical analyses in SPSS, version 7.5, 1995). I used a uniform distribution because it corresponds to the null hypothesis that the spatial distribution of behavioral records (i.e., grazing) is random with respect to water.

For each herding day, I defined the herding radius as the maximum distance from home at which a herd was observed during that day (see the top panel of Fig. 3). The factors affecting herding radius (distance to water, labor, herd size, and the density of other settlements) were analyzed using linear regression.

To calculate settlement densities I entered the coordinates of all cattle-keeping households in the study area ($N = 150$) into the GIS as text files. Next, the entire area within 9 km of the 24 focal households was broken

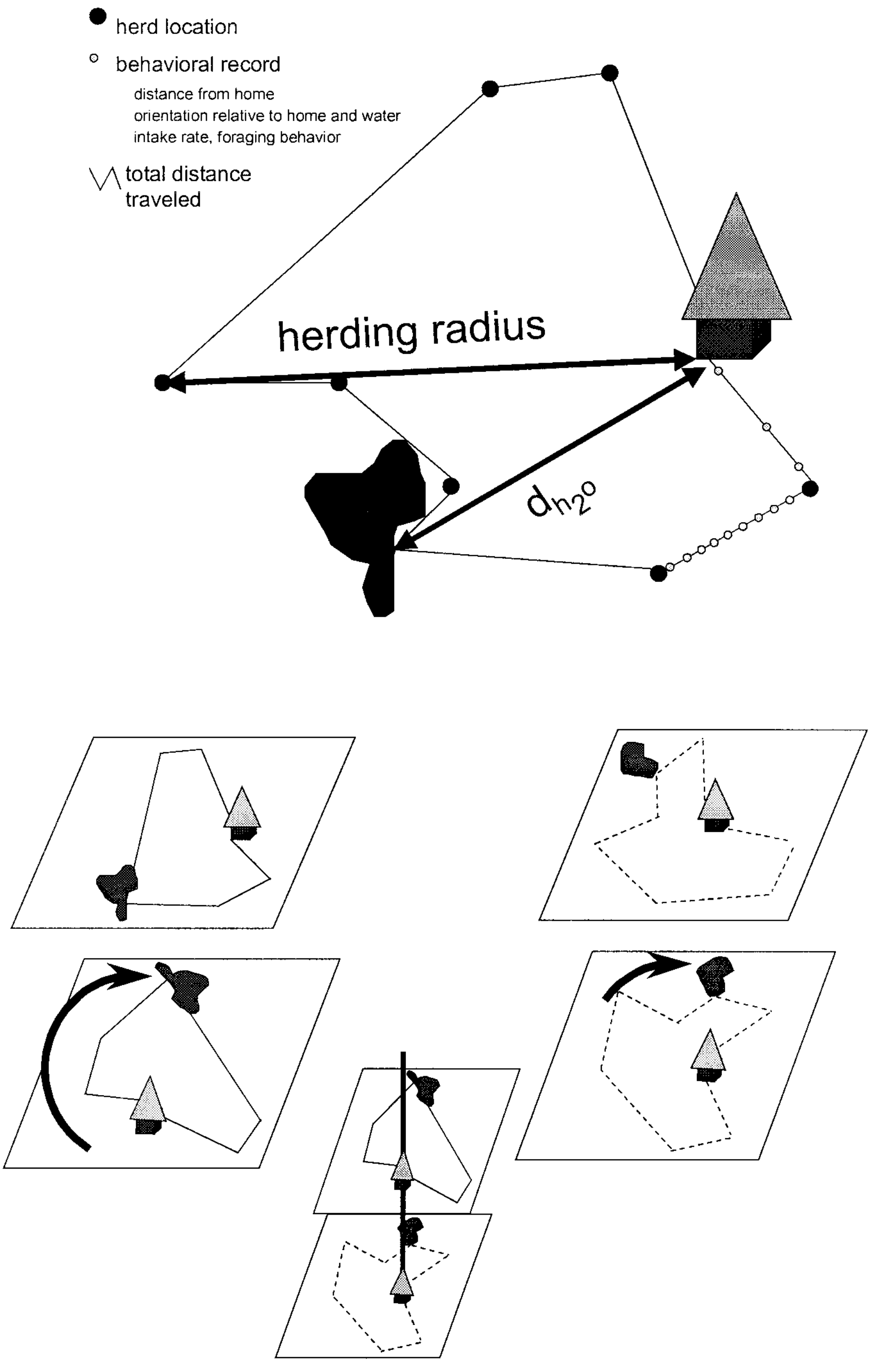

Fig. 3. An illustration of the data collected for each herding day (above) and its manipulation in order to compare different households' movements relative to water (below). See text for details.

up into 250 meter grid cells. I chose 9 km as a boundary because this was the maximum distance from home herds were observed to travel, so it is a conservative estimate of the entire area available to pastoral herds. I then used the GIS to calculate the density of settlements within two kilometers of each grid cell. This calculation used all 150 settlements in the study area, not just the 24 focal households. Because the majority of grazing occurred within two kilometers of home, this distance includes an ecologically relevant portion of the landscape without obscuring local heterogeneity.

I analyzed the spatial distribution of grazing relative to settlement densities by comparing the settlement densities in areas used by herds to those available to them. If herders show a preference for high or low settlement densities, these distributions will differ significantly. Under the null hypothesis, herders will show no preference, and use will occur in proportion to what is available. Preference values for each of 21 equal classes of settlement densities were calculated as $(O - E)/(O + E)$ where O is the proportion of behavioral records in each class, and E is the proportion of area occupied by that class in the entire area available to herds. This index ranges from -1 to 1, indicating strong avoidance and strong preference, respectively.

RESULTS AND DISCUSSION

I divide this section into two parts. First, I report the household-level factors affecting the herding radius (i.e., how far herds travel from home) and the distribution of grazing within the herding radius. In the second section I report the different measures of productivity resulting from different herding practices. Specifically, I examine how traveling farther from home (herding radius), keeping larger herds and living in or using densely settled areas affect herd productivity (intake rates and foraging behavior, milk yields, and body condition).

What Affects How Far Herds Range from Home?

As mentioned earlier, Sukuma settlements are not always in close proximity to water; households' distances to perennial water ranged from just over 500 meters to just under four kilometers. Distance from the household to water was the strongest predictor of the dry season herding radius (Fig. 4 and Table I). The fact that most points in Fig. 4 cluster along the line of x = y implies that during the dry season herds mostly travel only as far as their water source. Recall that the herding radius is ecologically significant because it defines the overall area affected by grazing as well as the extent of overlap between nearby households. Therefore, water availability is an important determinant of the landscape-scale distribution of grazing. This portion of the analysis was carried out only for dry season herding days, because water was available virtually everywhere during the wet season. Most studies of water availability have been in pastoral ecosystems with far less rainfall (c. 100–200 mm p.a.; see Knight, 1995; McCabe, 1990b; Nyerges, 1982; Verlinden, 1997; Western, 1975). The results presented here suggest that even in a relatively wet area receiving about five times the rainfall of more arid pastoral systems, the distribution of water influences land use and therefore is critical in modeling or assessing the impacts of pastoral grazing.

Sukuma herders report that the size of a herd affects its requirements and how it is herded, so I examined whether the effect of herd size is apparent in landscape-scale daily herding practices. Herding radius in the dry and early wet seasons and when all seasons were considered together was (positively) affected by the size of a household's herd. This effect could be spurious if the owners of larger herds lived farther from water, but this

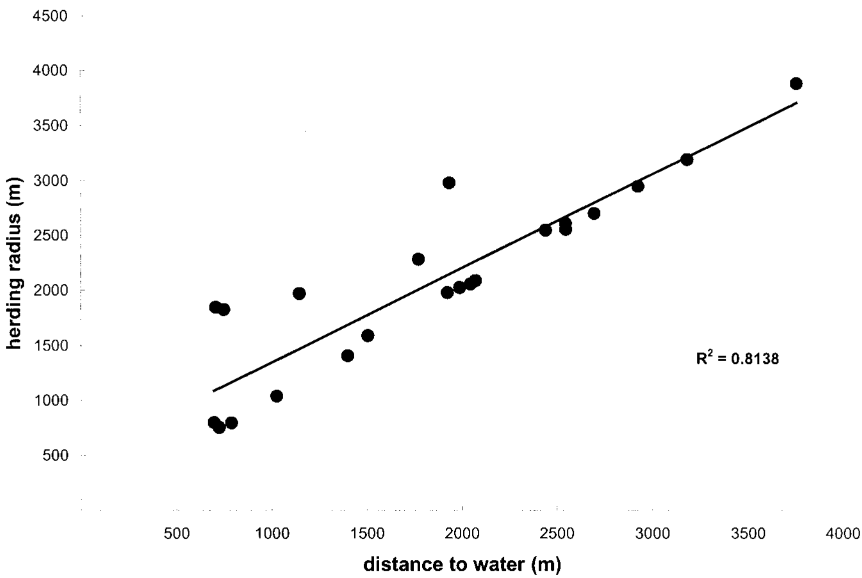

Fig. 4. Herding radius vs. each household's distance to water during the late dry season.

Table I. Factors Affecting Herding Radius and Leaving Times[a]

Predictor variable	Response variable	Season	r^2	P value
Distance to water	Herding radius	Dry	0.814	<0.005
Herd size	Herding radius	Whole year	0.177	<0.005
		Dry	0.522	<0.005
		Dry (mult. reg.)	t =0.717	n.s.
		Early Wet	0.483	<0.005
		Late Wet	0.086	n.s.
Labor	Herding radius	Dry	0.0	n.s.
		Early Wet	0.002	n.s.
		Late Wet	0.0	n.s.
	Leaving time	Dry	0.004	n.s.
		Early Wet	0.0	n.s.
		Late Wet	0.013	n.s.
Labor demand	Herding radius	Dry	0.029	n.s.
		Early Wet	0.016	n.s.
		Late Wet	0.056	n.s.
	Leaving time	Dry	0.013	n.s.
		Early Wet	0.001	n.s.
		Late Wet	0.0	n.s.
Area cultivated	Herding radius	Dry	0.023	n.s.
		Early Wet	0.006	n.s.
		Late Wet	0.036	n.s.
	Leaving time	Dry	0.002	n.s.
		Early Wet	0.012	n.s.
		Late Wet	0.002	n.s.
Settlement density	Herding radius	All Seasons	0.12	n.s.
		Dry	0.001	n.s.
		Early Wet	0.084	n.s.
		Late Wet	0.170	n.s.

[a]Significance is reported when $P < 0.05$.

was not the case since herd sizes, which ranged from 12 to 224 animals, were not correlated with a household's distance to water ($r^2 = 0.0019$, $P = 0.843$). However, in the dry season if herd size is analyzed as part of a multiple regression including distance to water, its effect was no longer statistically significant. This is understandable given the strong effect that the distance to water has on dry season herding radius. The reasons why larger herds travel farther are complex, involving herd productivity and the foraging behavior of individuals in large and small herds. For this reason a thorough discussion of the effects of herd size is presented after the productivity data.

Another factor potentially affecting how far herds travel from home is the amount of labor a household can devote to herding. This may be simply a function of the number of people in the household or of the competing labor demands from other aspects of household production. In the Sukuma case, cultivation may substantially drain labor from herding. Therefore, I investigated the effects of total household labor, the amount of land cultivated by the household and a ratio of the two. I examined whether these independent variables affected the herding radius and the times herds were let out to be herded (since weeding and cultivating is generally undertaken in the early morning). The results, summarized in Table I, show that none of the labor or cultivation variables had a measurable effect on daily herding practices.

The lack of relationships between labor, cultivation, and herding is surprising because cultivation is a contentious topic in policy debates surrounding pastoral production and conservation (e.g., see McCabe *et al.*, 1992), and given the well-recognized time constraints on herding (Bayer, 1990; Homewood and Rodgers, 1991), it seems logical that a time-consuming enterprise like cultivation would drastically change herding practices. Because all households in the study cultivate, these data cannot shed light on whether the initial adoption of cultivation qualitatively changes pastoral land use. However, these data do suggest that once cultivation has been undertaken, increasing or decreasing the area cultivated or the number of individuals participating has a minimal effect on herding practices. Since many households cultivate, even in groups once characterized as "pure pastoralists" (Brockington and Homewood, 1999; McCabe *et al.*, 1992; McCorkle, 1992; Dyson-Hudson and Dyson-Hudson, 1980), this result may have wider generality than is initially apparent.

The discussion above does not imply that labor is unimportant in pastoral households, only that it does not strongly affect daily herding practices. Labor is likely to be very important in the non-herding aspects of pastoral production, including milking, processing animal products, treating sick animals, marketing pastoral products, or in non-pastoral activities such as cultivation (Morton, 1990; Niamir, 1990; Fratkin and Smith, 1995). Amanor (1995) cites the importance of labor for herding in pastoral systems where seeds are collected or fodder is cut for livestock, but this assertion is not tested quantitatively (see Sieff, 1997; and Turner, 1999, for more on herding and labor). And cultivation does, of course, drastically change landscape structure in ways that certainly affect herding, so a lack of association with herding radii or the times herds leave home is obviously not an indication that cultivation is ecologically insignificant.

A final factor that could affect the distances herds range from home is the density of other cattle-keeping settlements around a household. More settlements (and more cattle) could deplete grazing resources and force herds to travel farther to find suitable forage. Focal households were situated in areas with densities spanning an order of magnitude, from .36 to 3.6 settlements km^{-2}, but this variation did not affect the herding radius in any single season or when the whole year is lumped (Table I). Settlement densities did however, affect the spatial distribution of grazing within the herding radius, so their importance is discussed below.

What Affects Patterns of Grazing Within the Herding Radius?

With the total area used by herds circumscribed by the herding radius, it is then necessary to examine the distribution of herding within that area. Two factors were considered here: the distribution of dry-season water and the distribution of cattle-keeping settlements. The distribution of grazing was skewed toward perennial water in the dry season and away from it in the wet season. Figure 5 shows the observed dry and wet season distributions of use (standardized relative to water).

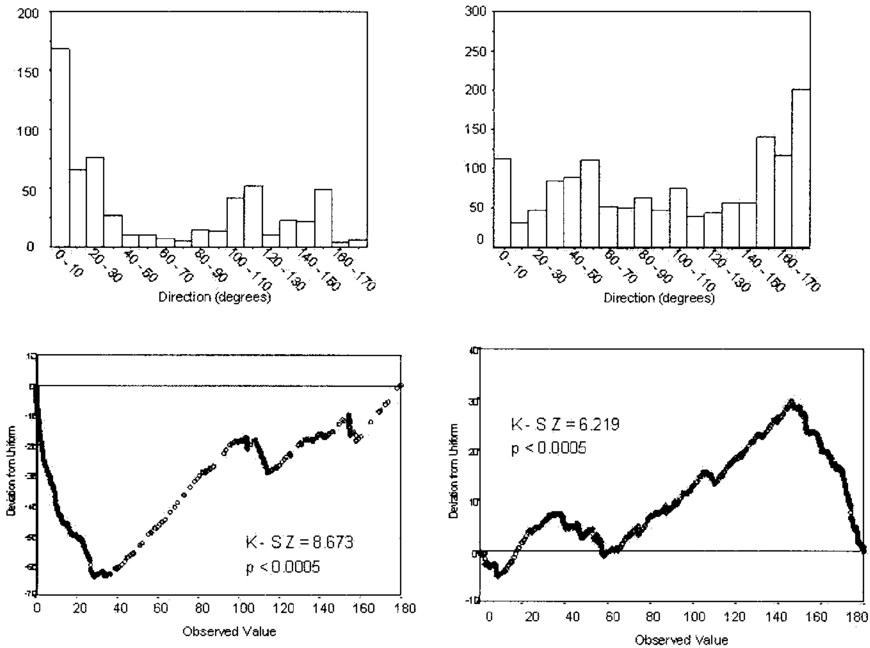

Fig. 5. Seasonal distributions (expressed in degrees) of herd locations relative to water. Dry and Wet season distributions are shown on the left and right respectively. Histograms (top) represent the number of behavioral records observed in each direction class. Directions are calculated for each behavioral observation according to its direction from home relative to that household's dry season water source (see text for details). Detrended Q–Q plots (bottom) show seasonal distributions plotted against a uniform distribution. Under uniform distributions of grazing relative to water, all points would fall on the horizontal lines. Kolmogorov-Smirnov Z statistics, based on the maximum deviation from uniform (on the vertical axes), confirm the seasonal differences shown in the histograms (dry: K–S $Z = 8.673$, $P < 0.0005$; wet: K–S $Z = 6.219$, $P < 0.0005$)

The seasonal shifts in grazing, taken together with the strong effect of water availability on herding radius, suggest that even in a relatively wet area like the Rukwa Valley, water is an important factor structuring the livestock grazing system. The results presented here also support Western's (1975) assertion that manipulating the distribution of water can influence pastoral land use systems. Again, this is noteworthy given the relatively greater rainfall in the Rukwa Valley. Clearly, water is a powerful but potentially dangerous management tool. Restricting access to water has been used to alleviate perceived resource conflicts between wildlife and livestock and minimize grazing in sensitive areas, but it has also led to intense conflicts between pastoralists and protected area managers (see reviews in Western, 1994; Lindsay, 1989). Another option may be to provide alternate water sources, but this can have serious negative consequences as well [Knight, 1995; Verlinden, 1997; but see Burkett and Thompson (1994) and Thrash (1998)]. McCabe (1990b) and others have described the social institutions that influence land use by regulating access to water. Water development should be pursued with care; an understanding of the social context in which access to water is regulated is critical to any management action.

An important caveat is that these results should not be interpreted as demonstrating a "piosphere effect" (defined as heavily grazed and often degraded area surrounding water points see Sinclair and Fryxell, 1985; Thrash, 1998). Recall that the animals in this study are herded and must be returned to their settlements each night. This constrains their ability to stay close to water, as unherded livestock and wild ungulates do (Estes, 1991; Lamprey, 1964; Western, 1975) and may be the reason why other pastoral systems tend not to show piosphere-type effects [Roe, 1984; and see Coppolillo (in press) for a more detailed discussion of the landscape-level grazing intensity when many households are aggregated].

Settlement density also affected the spatial distribution of herding, but perhaps surprisingly, herders' use was strongly skewed toward high and away from low density areas throughout the year (Fig. 6).[3] Seasonal distributions were not markedly different from the entire year, so a single analysis was performed. Preference values calculated for each class of settlement densities were strongly related to the lower limit of each density class (Fig. 7).

The year-round preference for high density areas is probably due to two factors: the integration of herding and cultivation and extremely high wet season productivity in undisturbed areas. During the dry season cattle are often grazed in harvested agricultural fields, which are all in higher

[3]Eliminating the lowest density class does not change the results observed.

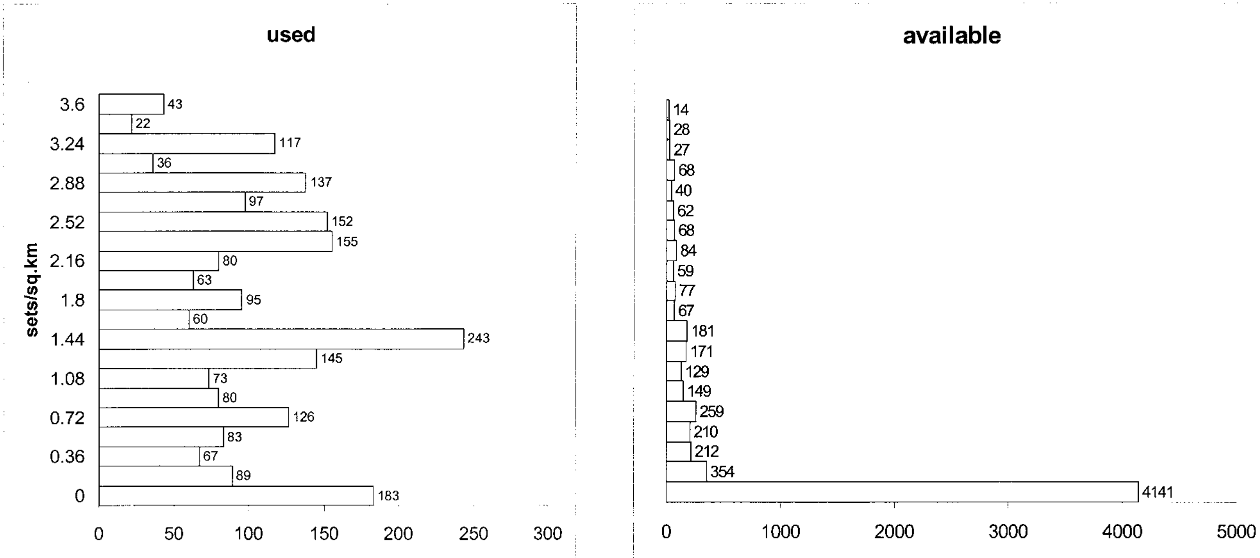

Fig. 6. Settlement densities within 9 km of households (right) and settlement densities actually used by households (left). Densities are the number of settlements per square kilometer. Used and available were compared using a chi-squared statistic, which confirmed their difference ($\chi^2 = 7541.37$, $P < 0.0005$).

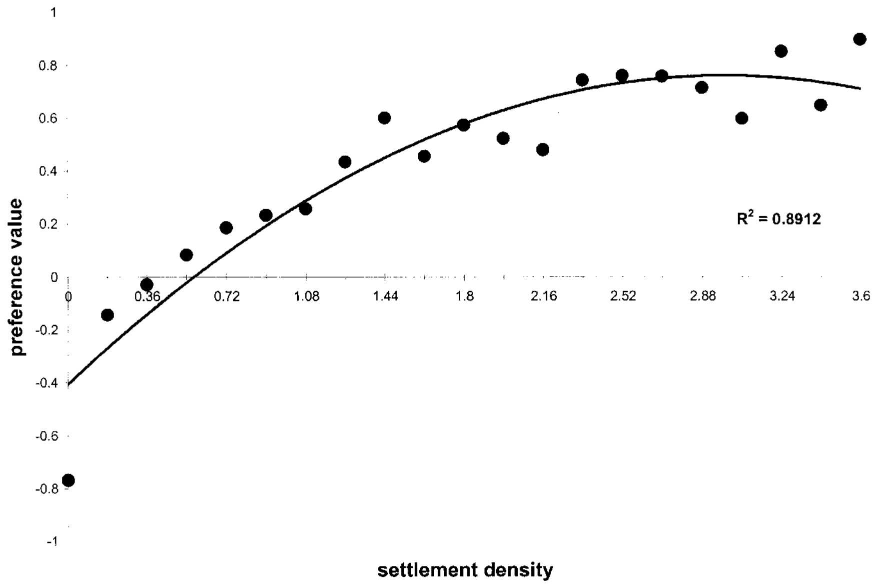

Fig. 7. Relationship between maximum settlement density in each class and the preference value for that class. Trend line is a quadratic best fit.

density areas. In general, herd owners graze their animals in their own cultivated areas (and can under traditional land tenure exclude all others from grazing in areas they have cultivated) but occasionally they pay Pimbwe horticulturalists for access to their fields as well. Wet season preference for more densely settled areas probably results from extremely high productivity which produces very tall and fibrous grasses. In some areas *Themeda triadra*, normally a very palatable grass, was over three meters tall during the wet season and consequently of little use as forage. Sukuma herders appear to be using high density (and often disturbed) areas as grazing lawns where shorter, more palatable forage can be found. Birley (1982) reports similar use of high density areas to keep standing vegetation low and reduce ectoparasite loads.

How Do Herding Practices Affect Cattle Productivity?

This section examines how variation in herding practices affects measures of herd productivity. Three primary questions are addressed: how does traveling farther from home, keeping cattle in large herds, and using areas of varying settlement density affect herd productivity? The measures of productivity used are herds' mean intake rates, foraging behavior, milk yields, and body conditions.

First, how does traveling farther from home affect herd productivity? Herding radius did not affect mean daily intake rates during any single season or over all seasons (Table II). Looking at individual behavioral records (not aggregated for entire days), distance from home had a significant negative effect on intake rates only in the late wet season (Table II), implying that being further from home was associated with lower intake rates. However, the effect only explained around 1% of the variance during the late wet season, so I conclude that traveling farther from home did not affect intake rates in a biologically meaningful way.

It is possible that more palatable forage is available farther from Sukuma settlements. This analysis would not resolve that difference because intake rates were calculated without regard to the species being eaten. However, if this was the case, herds that traveled farther would have similar intake rates but receive a more nutritious diet. Consequently, one would expect higher milk yields and body conditions for herds that traveled farther, but these were not observed. In fact, herding radius had no effect on body condition and a negative effect on milk yields (Table II). This effect was strong, with lactating females in herds that ranged farthest from home producing around one third of the milk produced by lactating females in herds that showed the smallest herding radii. This is not surprising given the fact that lactating ungulates are energetically stressed (Clutton-Brock *et al.*, 1982). Under the current circumstances it seems that traveling further provides little nutritional benefit, and energetic costs are responsible for

Table II. Seasonal Effects of Herding Radius on Productivity[a]

Response variable	Season	r^2	P value
Mean daily intake	All	0.029	n.s.
	Dry	0.144	n.s.
	Early wet	0.020	n.s.
	Late wet	0.136	n.s.
Individual intake	Dry	0.010	n.s.
	Early wet	0.001	n.s.
	Late wet	0.012	0.004
Milk yields	Early wet	0.032	n.s.
	Late wet	0.451	0.001
Herd's body condition	Dry	0.071	n.s.
	Early wet	0.133	n.s.
	Late wet	0.047	n.s.
Lactating females' body condition	Early wet	0.088	n.s.
	Late wet	0.183	n.s.

[a]Significance is reported when $P < 0.05$.

decreased milk production from lactating females. With increasing cattle densities, a decrease in range condition could eventually tip the balance in favor of traveling further for higher quality forage, but it appears that this is not yet the case in the Rukwa Valley. Analysis of vegetation across a gradient of cattle densities should help resolve this question and is currently underway.

Keeping cattle in larger herds had complex effects on productivity. Herd size did not have a significant effect on intake rates in any season when considering either mean daily intake rates or individual intake rates during behavioral records (Table III). However, herd size substantially affected foraging behavior. In the behavioral records, herd size was positively related to daily mean stepping rates over the whole wet season (Table

Table III. Effects of Herd Size on Productivity[a]

Response variable	Season	r^2	*P* value
Mean daily intake	All	0.039	n.s.
	Dry	0.043	n.s.
	Early wet	0.070	n.s.
	Late wet	0.001	n.s.
Individual intake	Dry	0.011	n.s.
	Early wet	0.005	n.s.
	Late wet	0.001	n.s.
Mean daily stepping rate	Dry	0.003	n.s.
	Early wet	0.672	<0.0005
	Late wet	0.311	0.006
Steps during feeding bouts	Dry	0.066	n.s.
	Early wet	0.294	0.007
	Late wet	0.213	0.027
Steps during walking bouts	Dry	0.004	n.s.
	Early wet	0.601	<0.0005
	Late wet	0.249	0.015
Number of walking bouts	Dry	0.008	n.s.
	Early wet	0.641	<0.0005
	Late wet	0.361	0.002
P Animals Feeding	All	0.064	0.039
P Animals Walking	All	0.077	0.023
Milk yields	Early wet	0.033	n.s.
	Late wet	0.014	n.s.
Herd's body condition	Dry	0.042	n.s.
	Early wet	0.197	0.034
	Late wet	0.060	n.s.
	Whole wet	0.017	n.s.
Lactating females' body condition	Whole wet	0.005	n.s.

[a]Significance is reported when $P < 0.05$.

III). Herd size was also positively related to the mean number of walking bouts (the number of times individual animals took greater than 10 steps without a bite) over the whole wet season.

Neither the stepping rate nor the mean number of walking bouts were related to herd size during the dry season (Table III). This lack of association is not simply because all herds were traveling to water; this portion of the analysis excludes transit to and from water. It is worth noting that for small herds, stepping rates and the number of walking bouts were highest during the dry season. In fact, the lack of association in the dry season is explained by the fact that small herds' stepping rates and walking bouts were as high as those of large herds. In other words, during the wet season it pays (through decreased walking) to keep animals in smaller herds, but during the dry season, all herds have high stepping rates.[4] This suggests an interaction between seasonal resource availability and herd size.

To summarize, herd size did not affect intake rate but large herds spent more time walking and less time feeding. It follows logically to ask why large herds walk more. Increased walking seems to stem from the fact that within large herds there are always a few individuals not actively feeding but walking from one feeding station (sensu Bailey *et al.*, 1996) to the next, leaving other animals behind. Because individuals tend to stay within a certain part of the herd (i.e., the front, middle, or back), they are often forced to stop feeding and walk to their usual position. These are the "walking bouts" reported above. This leap-frog behavior by individuals within the herd keeps large herds constantly moving. As mentioned earlier, increased walking is likely to affect animals' overall energy balance, and if the energetic costs of walking are not offset by greater resource availability in areas farther from home, it is likely responsible for the lower body condition of larger herds and lower productivity from herds that travel farther.

The increased walking also helps to explain why large herds traveled farther in the late dry and early wet seasons. The process described above precludes large herds from using smaller high quality patches close to home because the herd simply moves through them too quickly or they provide an insufficient number of feeding stations to occupy the whole herd at once. The result is that large herds end up using larger patches farther from home.

Given the differences in feeding behavior one might expect to see differences in milk yields associated with herd size, but herd size did not

[4]Breaking the overall stepping rate down into steps taken during walking bouts and steps taken during feeding bouts shows that herd size affected both stepping rates throughout the wet season and had no effect on either stepping rate during the dry season (Table III). These results were corroborated by the scan samples, which showed that across all seasons larger herds had a significantly smaller proportion of animals feeding (around 10% fewer) and a significantly larger proportion of animals walking (about 15% more).

affect milk yield during the early or late wet seasons (Table III). When analyzed across the whole wet season, herd size was not associated with lactating females' or the whole herd's body condition. However, looking at individual seasons, herd size did have a significant negative effect on the whole herd's body condition during the early wet season (Table III). This is a critical time for many pastoral animals since their body condition is still low from the dry season and they must endure cold and rain before realizing the benefits of better forage.

The increased traveling of large groups and productivity costs of travel are both consistent with other studies. Homewood and Rodgers (1991) found that milk yields dropped off sharply as the distance herds traveled increased. In primates, Altmann *et al.* (1993) found that baboons' body condition was lower in groups that ranged further, and Isbell (1991) and Isbell *et al.* (1998) report that larger groups of patas and vervet monkeys ranged further per unit time. The negative relationship between herding radius and body condition presented here contrasts with the findings of Western and Finch (1986), who report that steers were able to mitigate the effects of increased traveling by lowering their metabolism. A probable explanation for the difference between their results and those presented here is that Western and Finch (1986) focus only on steers. It is unlikely that other cattle, particularly energetically stressed lactating females, would be able to respond to increased travel in a similar manner.

Another consideration is that large herds' body condition was lower in the early wet season, which is the time when Sukuma herders report that disease takes the most severe toll on their animals. Taken together, the lack of resource scarcity and extensive use of high density areas suggest that disease may also be contributing to the decreased body condition in large herds. Rawlings *et al.* (1994) and Watcher *et al.* (1993) have shown that land use and livestock densities can affect the densities of tsetse flies. Grootenhuis and Olubayo (1993) also report increases in ectoparasite loads for wildlife living in association with livestock. Since each herd returns to the same enclosure and watering hole each day, larger herds may encounter a more substantial challenge from parasites. Future research should focus on disentangling the effects of herd size, herding practices, and settlement densities on disease interactions among pastoral herds.

The herd size effects reported here also cast light on the practice of herd splitting. Other pastoralists, particularly those living in arid environments and relying heavily on their herds for subsistence, split herds more extensively by species and even reproductive status (Coppock *et al.*, 1986a; McCabe, 1994; Nyerges, 1982; Sieff, 1997). Herd splitting allows them to tailor herding to specific species' needs (e.g., Coppock *et al.*, 1986b), and take advantage of differences in species' feeding ecology and behavior (e.g., Nyerges, 1982). The data presented here suggest that even within single-species herds, limiting group size appears to help herders reduce the distance their animals walk while foraging.

A final question is whether living in and/or using densely-settled areas affects herd productivity. The density of other settlements around households did not affect mean daily intake rates when examined over the entire year (Table IV). When looking at only the dry season, settlement density did have a negative effect on mean daily intake rate, but this relationship did not hold for the wet seasons. A related question is whether traveling to areas with lower settlement densities provides higher intake rates. To answer this question I examined the relationship between intake rate during individual behavioral records and the settlement density at the location of each record. There were no significant relationships. Further, the settlement density around focal households did not affect milk yields (Table III). When looking at the entire herd's body condition, settlement density had a significant positive effect during the dry season but not the wet seasons. Lactating females' body condition was positively related to settlement density during the early wet season and unrelated to settlement density during the late wet season (Table III).

Two apparently inconsistent results were that dry season daily intake rates were negatively related to households' settlement density, but spatial analysis of the individual behavioral records showed no relationship between settlement densities and intake rates. Furthermore, use was strongly skewed toward higher settlement densities throughout the year, including the dry season, and body condition was positively related to settlement

Table IV. Effects of Settlement Density Productivity[a]

Response variable	Season	r^2	P value
Mean daily intake	All	0.003	n.s.
	Dry	0.834	0.004
	Early wet	0.042	n.s.
	Late wet	0.002	n.s.
Individual intake	Dry	0.008	n.s.
	Early wet	0.000	n.s.
	Late wet	0.004	n.s.
Milk yields	Early wet	0.051	n.s.
	Late wet	0.099	n.s.
Herd's body condition	Dry	0.189	0.030
	Early wet	0.028	n.s.
	Late wet	0.006	n.s.
Lactating females' body condition	Early wet	0.199	0.049
	Late wet	0.042	n.s.

[a]Significance is reported when $P < 0.05$.

density during the early wet and dry seasons. Reconciling these results may be possible in light of two observations: first, during the dry season all cattle were herded from sunrise to sunset, implying that they were time limited; and second, high density areas tend to be nearer to water. Proximity to water may give herds from densely settled areas more time to feed because travel time to and from water is shorter. Consequently, herds living at high densities could feed less intensely (obtaining lower mean intake rates) over a longer grazing time as they travel less than herds living at lower settlement densities. Bayer (1990) reports that time constrained pastoral animals fed more consistently and intensely than unconstrained animals to maintain similar levels of productivity. Thus, herds can experience lower mean intake rates and still have better body condition during the dry season.

SUMMARY AND CONCLUSIONS

The objectives of this study were to examine the factors affecting the spatial patterns of daily herding among Sukuma agropastoralists living in the Rukwa Valley, and to assess how different land use practices map onto measures of herd productivity. The results, summarized schematically in Fig. 8, demonstrate considerable household-level variation in herding practices and in resultant levels of cattle productivity. The data presented here support the contention that individual-level analyses reveal significant variation not apparent at the population level.

In the Rukwa Valley, the distribution of dry season water structured the landscape-scale distribution of grazing throughout the year, not just during the dry season. Water availability strongly affected the distances herds ranged from home in the dry season and the distribution of grazing around pastoral settlements. Since the timing of grazing may be as important as herbivore density (Westoby *et al.*, 1989; Walker, 1993), the location of water may affect rangeland vegetation both near and far from water sources.

A second noteworthy result is that herders showed strong preferences for densely settled areas relative to what is available. This has a number of implications. First, it highlights the spatial aggregation of livestock and agrarian production. Use of high density areas reflects herders' choice of harvested and fallow agricultural fields for grazing. This means that livestock production may indirectly affect landscape structure since the amount of land under cultivation and in fallow, the ratio of the two, and their spatial configurations may reflect herding as well as agrarian considerations. Herders' preference for high density areas also makes encroachment into surrounding, relatively undisturbed areas unlikely (provided, of course, that these areas remain unsettled and uncultivated). Both landscape structure and the potential for encroachment are important aspects of pastoral sys-

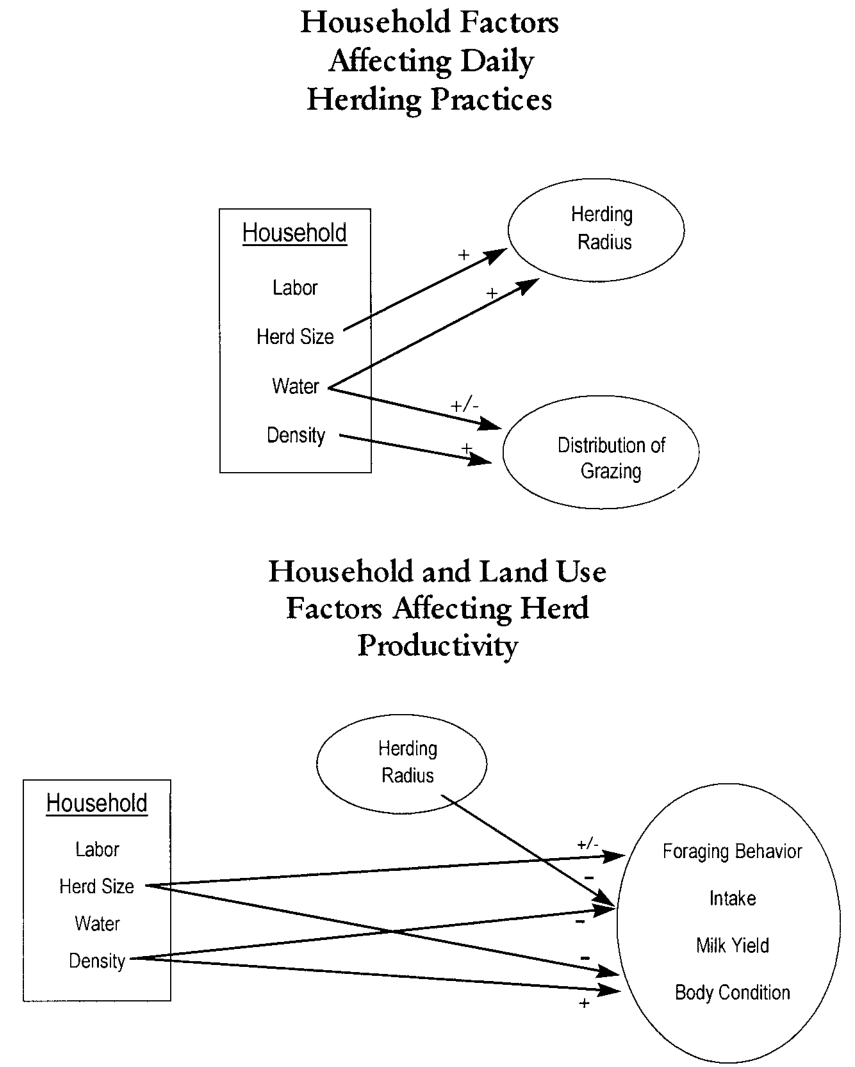

Fig. 8. Diagrammatic summary of household-level factors affecting herding practices (top) and land use and household-level factors affecting herd productivity (bottom).

tems for biological conservation, given the fact that pastoral and agropastoral peoples live adjacent to or surrounding nearly all of East Africa's national parks and game reserves (Enghoff, 1990).

The relationships between herding practices and productivity were more complex. Individuals from larger herds were observed to walk more while actively foraging and engage in more walking bouts (taking ten steps without taking a bite). However, the effects of large herds' increased walking were not apparent in intake rates or milk yields. The increased walking of large herds may explain why they range farther from home and highlight the importance of herd splitting.

To what extent can these results be applied to other pastoral systems? Interestingly, similar shifts in grazing toward water in the dry season and away in the wet season were documented by Western (1975) in an arid ecosystem (Kajiado District near Amboseli N.P., Kenya). Since the Rukwa Valley receives nearly five times the rainfall of the Amboseli Basin, it is possible that this is a generalized phenomenon which should hold for most or all pastoral systems. One exception may be when herders alternate forage and watering days and travel in different directions on each day (Western and Finch, 1986; Homewood and Rodgers, 1991). The ubiquity of herd splitting among other pastoral groups suggests that the effects of herd size observed in this study are also important in other pastoral systems.

All pastoral groups are essentially central-place foragers when considered at a daily time scale because they come and go from the same homestead each night. The analytical methods presented here can be applied to any pastoral herding situation given a known daily starting point. In fact, this method could be applied to any number of resource systems where impacts are distributed around a focal point. Applying this method comparatively to other pastoral groups will provide a much greater level of generality and a broader understanding of pastoral systems. Longer term studies capturing inter-annual variation through drought and wet years and experimental approaches will undoubtedly enhance our ability to recognize the mechanisms driving herding systems.

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