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Full Length Research Paper

Range use and dynamics in the agropastoral system of southeastern Kenya

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Occurrence of equilibrium and non equilibrium system dynamics in semiarid environments present serious management challenges. In these areas, resource management strategies are increasingly based on equilibrium rather than non equilibrium dynamics that assume simple system dynamics and strong coupling of animal-plant responses. This management approach underlies increasing trends of range degradation and low livestock productivity in these environments. To reverse these trends dictates greater understanding and alignment of grazing resource extraction strategies in space and time to prevailing system dynamics behaviour. In this study, range use patterns by free ranging herds under agropastoral herding were studied in two cycles of four consecutive grazing periods, in semiarid southeastern Kenya. The bites count and herd locations per area methods were used. While grazing thresholds in the system were derived from biweekly sward biomass measured by the quadrant technique in the growing period and stocking rates applied to a growth-consumption rate model. The analysis tested the responsiveness of the agropastoral herding strategies to the predominant system dynamics in the area. In this environment, high rainfall variability ranging from 71 to 98% is experienced across years and seasons, pointing to non-equilibrium dynamics in the system. The agropastoralists practiced seasonal range use and tracking strategies. During the dry season, areas of concentrated drainage; river valleys, bottomlands and ephemeral drainage ways absorbed a greater grazing load, taking 57.1 to 60% of the grazing time by the animals. In contrast, areas of limited moisture concentration, the open sandy/clay plains, were mainly exploited in the wet season and accounted for 52.6 to 55.6% of the grazing time. The agropastoralists tracked forage availability through use of multispecies livestock (cattle, goats and sheep) that exploited different grazing resources in space and time. These range use patterns and strategies tend to stabilize nutrient and energy flow to livestock and thus productivity throughout the seasons. Based on the growth-consumption rate model, grazing thresholds in the system are achieved at 13800, 13000, 4000 and 12300, 4600 and 12000, and 5600 and 11000 kgha^{-1} of grass biomass at, 2.5, 5, 7, 8 and 10 TLUha^{-1}, respectively. 7 TLUha^{-1} represent the upper stocking rate limit in the system during the growing period. In this system, resource use strategies are in line with the predominantly non-equilibrium system behaviour. However, sedentary land use interventions and limiting farm sizes that restrict livestock mobility and negatively affect grazing resource diversity will undermine system stability and sustainable livestock production in the area.

Key words: Agropastoralists, range use, system dynamics.

INTRODUCTION

Rangelands in Africa are largely inhabited by the pastoral people and cover 60% of the continent's land area. In these areas, livestock is the main livelihood source, where over 1.9 and 0.6 tropical livestock units (1TLU is equal to an animal weighing 250 kg) per person per square kilometer are realized in the pastoral and agropastoral areas, respectively. However, agropastoralists, like pastoralists all over the world and especially in sub-Saharan Africa, are faced with problems of land degradation and low livestock productivity. Human-induced rangeland de-

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gradation is widespread, with 31% of the area estimated to suffer severe loss of productivity (de Leeuw and Reid, 1995). The sources of degradation include inappropriate cultivation of marginal areas, deforestation, and grazing. Increasing trends of land degradation in the grazing environment exacerbates low livestock productivity. Grazing contributes about 34.5% of the total soil degradation (Greijn, 1994) in the African rangelands. In Kenya, high rates of soil loss of up to 50 tonnes per hectare per year from degraded grazing land in semiarid areas are common (Nyaoro, 1996), and over 50% of natural pastures in the southern rangelands of Kenya are degraded (Mnene, 2004).

In rangelands, land degradation is largely attributed to the tragedy of the commons phenomenon (Hardin 1968) or prevailing aridity (Ellis et al., 1993). Approaches for addressing land degradation in the past were centred on western models of rangeland management practices that emphasized determining grazing plans and stocking rates (Perrier, 1994). In Kenya, for example, the government policy interventions focused on land privatization and appropriation to create grazing blocks and ranching schemes. However, evidence indicates that projects modeled on the ranch approach have often generated negative rates of return, and have favoured wealthier households (McCarthy and Swallow, 1999).

Livestock production problems at the agropastoral level are largely attributed to inadequate understanding of the ecology of semiarid environments, particularly the temporal and spatial variability of rangeland production, range use patterns and the role of mobility in sustaining livestock production (Ellis and Swift, 1988). In these environments, variations in forage quantity and quality are determined by rainfall variability (Sinclair, 1975; Frank and McNaughton, 1998; Knapp et al., 2001) and soil fertility gradients (McNaughton, 1990). These environmental gradients lead to variability of grazing resources in space and time, giving rise to nutrient rich or nutrient poor grazing areas. This situation makes a tracking grazing strategy to be better suited to these environments (Sandford, 1983; Behnke and Scoones, 1993). Under this strategy, grazing animals move along their grazing circuits, seeking out productive and nutrient rich plant species. They match grazing time per plant community to the forage resource available (Senft et al., 1987), spending less time per feeding area as desirable forage availability declines (Ruyle and Dawyer, 1985). Thus, animals adjust their vegetation utilization patterns in relation to the vegetation's productivity y and nutrient content (Bailey et al., 1996).

In the recent past, this resource use strategy is under pressure from increasing tendencies for sedentary livestock keeping and limited mobility occasioned by individualization and privatization of grazing land. In this case, resource management strategies are increasingly based on equilibrium system dynamics that assumes, simple system dynamics, where forage flow is relatively constant and predictable and animal-plant responses are strongly coupled (Tainton et al., 1998). Thus, the occurrence of equilibrium dynamics in these semiarid areas precipitates negative vegetation shifts under high livestock densities (Coppock, 1993). However, not all range sites experience equilibrium system dynamics, some experience non-equilibrium system behaviour or both (Briske et al., 2003). Therefore, understanding of grazing resource extraction patterns in space and time and system dynamics is central to designing of strategic interventions to enhance livestock productivity and protect the environment. Yet, few studies (Coughenour et al., 1985; Coppock et al., 1986; Ellis and Swift, 1988) in Kenya have focused on grazing resource extraction patterns in arid and semiarid areas (ASALs). This calls for further analysis of the diverse production systems and attendant resource use strategies in ASALs to ascertain and align them with dominant system dynamics. This study analyzed the responsiveness of the grazing resource extraction patterns and strategies to dominant system dynamics and determined the grazing thresholds to protect the environment in the agropastoral system of southeastern Kenya.

MATERIALS AND METHODS

Study area

The study was conducted in Kibwezi Division of Makueni District during 2003/2004 period. The district covers about 7,263 sq. km (RoK, 1994), and lies between 1.5^o – 3^{o}S and 37^o - 38.5^{o}E. It is bordered by Kitui District to the east, Taita District to the south, Kajiado District to the west and Machakos District to the north. The district receives an average annual rainfall of 500 mm in the lowlands in the south and 1200mm in the highlands in the north. The rainfall is characterized by small total amounts, strong seasonal and bimodal distribution, with high temporal and spatial variability between seasons and years. Annual mean temperatures experienced in the District range between 19 to 26^{o}C (Jaetzold and Schmidt, 1983).

The district is classified into six agro-climatic zones (ACZs) (Sombroek and Braun, 1980). The dominant ones are IV and V where risks of crop failure are high. Based on ACZ, the district has three main soil types: AEZ UM2/LM2 is dominated by red clay on hills and sand soils and black cotton soils on lowlands; AEZ LM4/LM5, has red clay and black cotton soils; and AEZ UM3/LM3 has mostly black cotton soil (Jaetzold and Schmidt, 1983). The natural vegetation is woodland and savanna, with several tree species, mainly: *Acacia* sp (A) such as *Acacia tortilis* (Forsk) Hayne and *Acacia mellifera* (Vahl) Benth, *Commiphora africana* (A.Rich) Engl, *Adansonia digitata* Linn and *Tamarindus indica* L. Shrubs include *A. mellifera*, *Acacia senegal* (L) willd, and *Grewia* spp. The main perennial grasses include *Cenchrus ciliaris* L, *Chloris roxburghiana* Schultz, *Panicum maximum* Jacq, *Eragrostis superba* Peyrs, *Digitaria milanjiana* (Rendle) Stapf and *Enteropogon macrostachyus* Benth.

Kibwezi Division covers 47% of Makueni District and has a total area of 3,400 km^2 with a human population density of 92 persons per km^2 (Rok, 2002). It lies in the central part (Figure 1), in ACZ IV and V of the district described as low potential maize zone, and high potential livestock and millet zone; and very low potential maize zone and medium potential livestock and millet zone, respec-

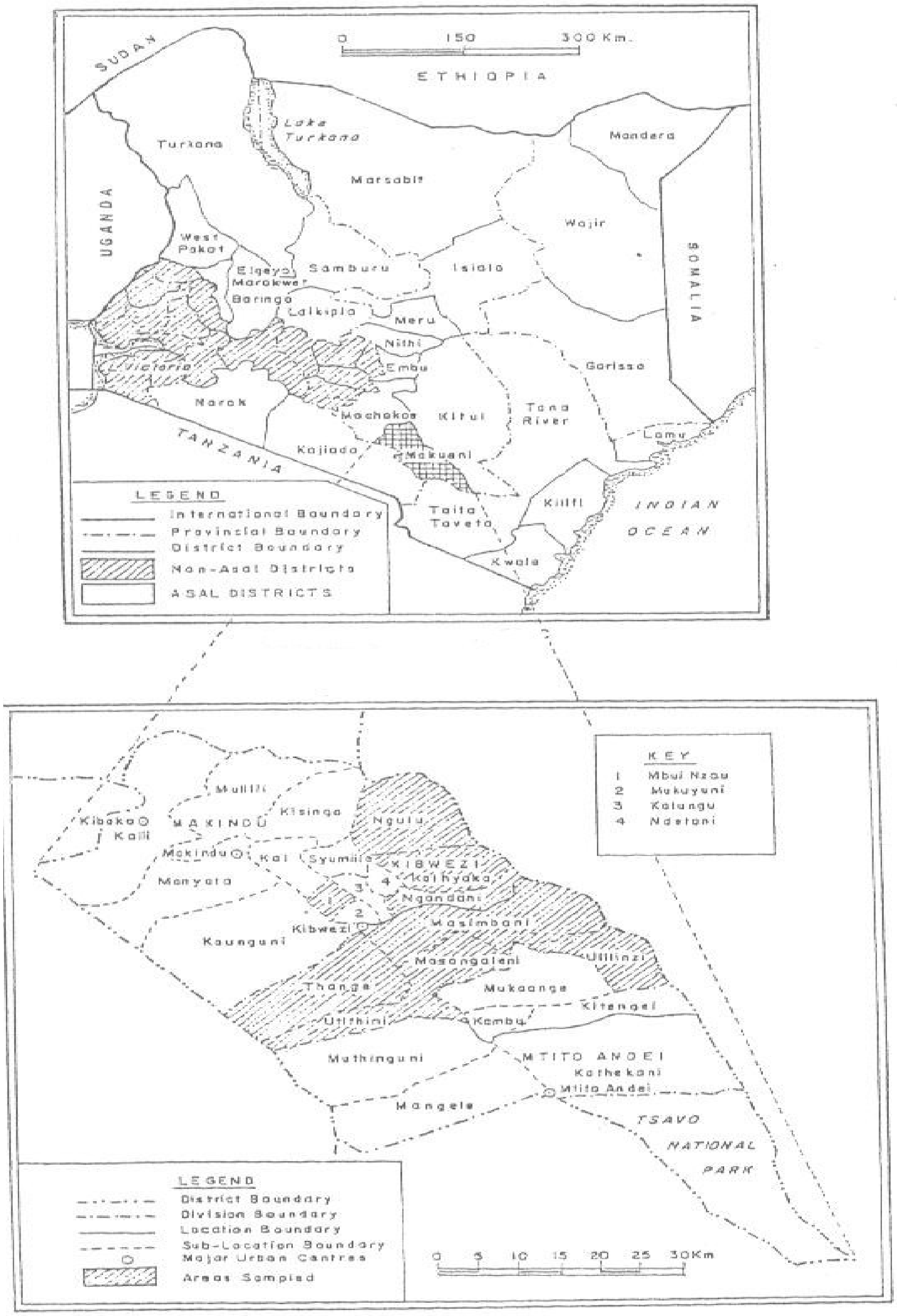

Figure 1. The location of Kibwezi Division in Kenya and areas sampled.

tively (Jaetzold and Schmidt, 1983; Rok, 1989). The area was not settled by people until the 1930s due to its low agricultural potential and heavy infestation by tsetse flies. Thereafter, high population pressure in the high potential areas forced people to move in.

The Kamba agropastoralists are the main ethnic inhabitants in the study area. Their mainstream economic activity is raising livestock and cultivating cereals and pulses (Tiffen et al., 1994). Farm sizes in the study area ranges from 2 to 14 acres with over 50% of the inhabitants holding less than 10 acres. Land tenure is mainly freehold. Livestock kept consists of local breeds mainly Small East African Shorthorn Zebu cattle, Red Maasai sheep and East African goats. The animals are kept under free range/herding in defined household grazing areas. However, sometimes in the dry season livestock are temporarily moved into cultivated fields to utilize crop residues. The crops grown include different drought tolerant varieties of maize, sorghum, millet, pigeon peas and beans. Small-scale irrigation of horticultural crops is carried out in some parts of the division, especially along Athi River and its tributaries. In the study area, about 80% of the farmers practice mixed farming (crop/livestock production), with half of the land holding used for grazing. The production system is largely geared to subsistence production. Drought and famine occur every 7 to 10 years with high crop failures nearly every 2 to 4 years (Musimba et al., 2004).

Data collection

Samples consisted of three livestock herds in the Kibwezi community. The three herds were selected as follows; one main transect (road/footpath) cutting through each of the nine sub-locations of Kibwezi Division were taken. From the central place of each transect, 2 to 3 agropastoral households were picked on either side and identified at about every kilometer to give 5 to 6 households per transect. A total of 50 households were picked and arranged into a sampling frame. The first household was randomly picked using the table of random numbers. The next two were picked at equal_from the first one on the sampling frame to provide the study herds.

Data on the grazing patterns of cattle, sheep and goats were collected during mid and late grazing periods of two cycles of wet and dry seasons in sequence through daylong excursions. Three animals per species per herd balanced for weight and age were used to quantify feed selection by the bite count method (Backer and Hobbs, 1982). Two trained observers recorded simultaneously the bites by one animal at a time, alternately across species. Forage classes, plants and plant parts selected were recorded in 10 min feeding observations for each animal species, alternately. Sampling was done when the herds were actively grazing in the morning and afternoon. A total of 432 feeding observations were conducted and evenly distributed across species and season. Forage classes were categorized as perennial grasses, annuals, forbs, and woody plants (browse). The grazed sites, based on soil and vegetation type, water bodies, and topographic features and intensity of use during the grazing period were also recorded. The intensity of use was estimated as the number of herd locations per unit area. Herd locations per unit area reflect the duration of time a herd spends in an area. Herd locations were recorded in Universal Transverse Mercator coordinates (UTM coordinates define two dimensional, horizontal positions) every 15 minutes using a hand-held global positioning system (GPS). During the growing period, biweekly measurements of available sward biomass in the grazing environment were undertaken using 4 by 4 m randomly placed sample plots on 18 herd locations. These herd locations accounted for most of the grazing time. On each plot, available sward biomass was determined by clipping and weighing three different and randomly placed 0.25 m^2 rectangular quadrants at 2 cm (the observed minimum grazing stubble height) above the ground each time. Also, qualitative information on stocking rates in the area was collected from the households and climatic data was taken from Kibwezi meteorological field station.

Data analysis

Seasonal intensity of use of different herd locations was compared using descriptive statistics. A rainfall variability index was computed to reveal the likely pre-dominant system dynamics of the area (Ellis, 1994; Ellis and Galvin, 1994). Based on available pasture biomass, intake and stocking rate of grazing cattle, a generalized growth-consumption rate model was applied to describe the stability properties of the system. Two processes of plant production and consumption were considered. The rate parameters defined as growth rate and consumption rate dependent on the amount of available sward biomass were used.

The standard values and assumptions of the model used were based on seasonal pastures (Noymeir, 1978). The assumptions were that:

1. The growth rate of green biomass is a unique function of total green biomass. That is, growth rate of green biomass is a function of total green biomass.
2. The rate of consumption of green biomass by one animal is also a unique function of total green biomass. That is, the rate of consumption of green biomass by an animal is a function of total green biomass.
3. Net available green biomass is the green biomass production minus biomass consumption by a given animal population.
4. The end of the growing season occurs at a fixed time, which is independent of the grazing history and pasture dynamics during the season.
5. The parameters of the growth function are constant from the beginning of the growing season till its end, at which growth stops.
6. Growth rate is a ramp function of biomass minus a maintenance respiration loss rate, which is linearly proportional to biomass.
7. Consumption per animal is a ramp function of biomass.

Assumptions 4 and 5 on a finite growing season assume no variations in growth parameters within the season. Assumptions 6 and 7 specify the explicit functions for growth and consumption, in which the saturation of both processes, with respect to biomass, is abrupt rather than gradual.

For growth rate (G), the logistic function was used to give the rate equation given as question (1).

$$G = rgrV\ (1 - V\ /V_x) \tag{1}$$

Where G = forage growth rate ($kgha^{-1}d^{-1}$) of dry matter
rgr = relative growth rate (d^{-1})
V = pasture biomass ($kgha^{-1}$)
V_x = maximum attainable pasture biomass

For consumption rate (I), the inverted exponential function was used to give the rate equation given as question (2).

$$I = I_x(1 - e^{-\frac{V - V_r}{V_s - V_r}}) \tag{2}$$

Where I = intake rate of an animal (kgd^{-1}) of dry matter
I_x = maximum attainable intake rate of an animal ((kgd^{-1})
V_r = residual, ungrazable, pasture biomass ($kgha^{-1}$)
V_s = shape parameter ($kgha^{-1}$)

The dynamics of growth and consumption rates were examined by expressing them in similar units. This was achieved by multiplying the intake rate by the stocking rate (H)). Thus, consumption rate (C) on an area basis is defined as;

$$C = IH \tag{3}$$

From the above, C and G have same units. Plotting the consumption and growth functions on the same y axis against pasture biomass (V), the stability of the grazing system was examined for the growing period. For example, at any level of V, if G is greater, V increases; if C is greater, V decreases. Points at which the functions intersect are equilibrium points, giving stable or unstable equilibrium points.

The parameters, primary and standard values used to analyze

Table 1. Parameters, primary and standard values used in growth-consumption rate model

Parameter	Symbols	Units	Standard values	Primary values and range tested
Relative growth rate	rgr	Day^{-1}	0.04	-
Pasture mass	V	kgha^{-1}	-	2000-12000
Maximum attainable pasture mass	V_x	kgha^{-1}	12500	-
Maximum attainable intake rate of an animal	I_x	kgday^{-1}	10	-
Residual, ungrazable, pasture mass	V_r	kgha^{-1}	50	-
Shape parameter*	V_s	kgha^{-1}	500	-
Stocking rate	H	TLUha^{-1}	-	2.5-10

*Defines the best curve for a random variable with a probability density function having a variety of shapes. In this case, it is attained at intake-satiation biomass of the pasture

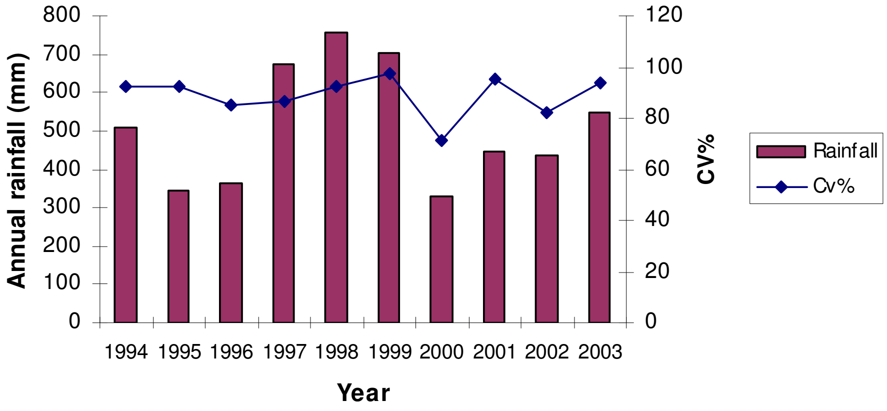

Figure 2. Annual rainfall and coefficient of variation in the study area.

the stability properties of the grazing system are presented in Table 1.

RESULTS

Rainfall characteristics

Figure 2, presents the annual rainfall and the intra-annual percentage coefficient of variation (CV %) of rainfall in the study area. Annual rainfall ranges from 328 to 756 mm. The coefficient of variation of rainfall ranges from 71 to 98%. In this area, the annual rainfall amounts are within the limits (300 – 600 mm) for semiarid environments. However, high rainfall variability was experienced across years even with those receiving higher rainfall amounts.

Grazing patterns and habitat use

Table 2, presents average percent grazing time spent by animals in various microhabitats during the wet and dry seasons. In the dry season, areas of concentrated drainage that included river valleys, bottomlands and ephemeral drainage ways absorbed the grazing load, taking 57.1 to 60% of the grazing time. Foothills/slopes and the open sandy/clay plains followed with 30 to 33% and 9 to 10% of grazing time, respectively. The open sandy/clay plains were mainly exploited in the wet season, accounting for 52.6 to 55.6% of the grazing time. Exploitation of the foothills/slopes was intermediate, but taking more grazing load in the dry season than in the wet season.

The animals exploited a wide array of plant species. Forage energy for cattle and sheep came primarily from herbaceous plants, while goats largely exploited woody plants. Goats, sheep and cattle utilized 25 to 44, 25 to 35 and 18 to 29 plant species, respectively. These constituted the primary plant-herbivore energy pathways. *E. macrostachyus* was the single largest energy pathway and accounted for 33.5% of the total energy intake of cattle. The other important grass resources were *P. maximum* (9.9%) followed by *E. superba* (7.3%). *Combretum exalatum* Engl and *Duosperma kilimandscharica* (Lindan) Dayton were the primary energy pathways that accounted for over 10% of total energy intake of goats with seasonal peaks of 18.5 and 17.2%, respectively. Sheep were largely mixed feeders, but *E. macrostachyus* (16.6%) and *Blepharis integrifolia* (L. f) Schinz (10.3%) were the primary energy pathways.

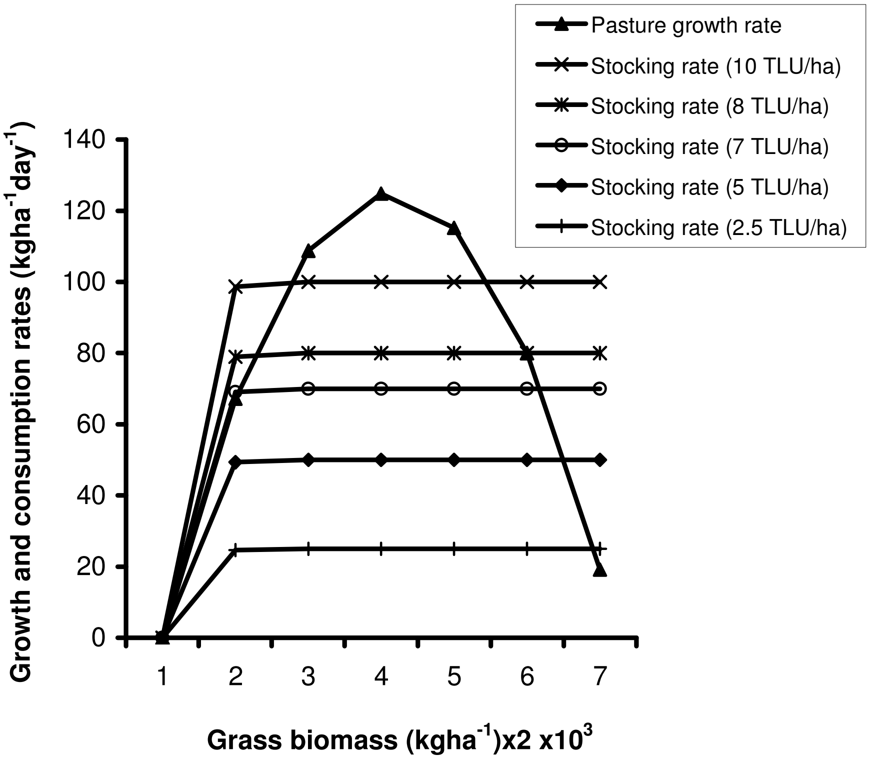

Figure 3. Growth-consumption relationships under five stocking rates

Table 2. Microhabitats and seasonal exploitation/grazing time of agropastoral herds.

	T1		T2		T3		T4	
Microhabitat	**No. of grazing station**	**% grazing time**	**No. of grazing stations**	**% grazing time**	**No. of grazing stations**	**% grazing time**	**No. of grazing stations**	**% grazing time**
Areas of concentrated drainage	12	60	12	57.1	4	22.2	5	26.3
Foothills/slopes	6	30	7	33.3	4	22.2	4	21.1
Sandy/clay plains	2	10	2	9.5	10	55.6	10	52.6
Total	20	100	21	100.0	18	100.0	19	100.0

Where T1 - mid dry (February and August), T2 - late dry (March and October), T3 - mid wet (April and November), T4 - late wet (May and December) season

Stability properties of the grazing system

The grazing area was characterized by a pasture sward of mixed composition, but mainly a perennial association of *E. macrostachyus, P. maximum* and *E. superba* that accounted for up to 82% of standing biomass during the growing period. Annuals accounted for less than 10%. The stocking rates in the grazing areas ranged from 0.09 to 6 TLUha^{-1}. Figure 3 illustrates the outputs of the stability model for the system. Figure 3 illustrates that grass growth rate initially increases rapidly, then gradually to a maximum before beginning to decelerate to zero as the end of the growing season approaches. Consumption rates generally increase with growth rate till the maximum satiation intake, that is, intake at which consumption is saturated. For the stocking rates tested (2.5, 5.0, 7.0, 8.0 and 10 TLUha^{-1}), satiation intake is achieved at 25, 50, 70, 80 and 100 kgha^{-1}day^{-1}, respectively. While, the equilibrium points are achieved at 13800, 13000, 4000 and 12300, 4600 and 12000, and 5600 and 11000 kgha^{-1} of grass biomass, respectively.

DISCUSSION

The high rainfall variability experienced in the study area makes rainfall to be erratic, unpredictable and unreliable. This high rainfall variability that exceeds 33% further suggests that system dynamics in the area are predominantly climate-driven and thus non-equilibrium (Ellis et al., 1993; Ellis, 1994; Ellis and Gavin, 1994). This has important implications for resource use and management strategies. In this case, rain fed crop production becomes highly risky and untenable, while livestock grazing should increasingly be based on tracking grazing strategies that aim to maximize on transient grazing resources in space and time.

The agropastoralists within their limited range followed a seasonal pattern of habitat use with defined user rights. They exploited different microhabitats that were designnated either as wet or dry season grazing areas. The dry season grazing areas tend to concentrate moisture and allow for more forage production into the dry season. These areas are key production sites in the system. Areas that tend to have limited moisture concentration were mainly exploited in the wet season. The transit sites (the foothills/slopes), were important in easing the grazing load in the dry season areas. This resource use strategy ensured that the habitat was exploited in a manner that sustained livestock production throughout the year.

The herds exploited a wide array of plant species. Different plant species have different phenologies. This makes the plants available for exploitation at different times. This variability in growth of plant species and exploitation ensures a steady energy flow from plants to the animals over time. Saunders (1978) observed that including a greater number of plant species stabilized a model food web. Also, McNaughton (1977) reported that compensating fluctuations in the abundance of co-occurring plant species stabilized total primary production against environmental disturbances. Thus, high species richness at the primary producer level reduce variations in aggregate biomass production and lead to stabilized energy flow in the grazing system (Tilman, 1996; Worm and Duffy, 2003). Furthermore, keeping different livestock species ensured a broad based forage resource extraction strategy that enhanced livestock productivity throughout the seasons.

At low stocking rates (up to 5 TLUha^{-1}), consumption rate lags behind pasture growth rate. Under this situation, at any point in the grazing system, pasture production is in excess of consumption and there is minimal grazing damage to the system. Grazing damage is only likely late in the growing period when there is minimal pasture production. At higher stoking rates (above 7 TLUha^{-1}), pasture growth rate initially lags behind consumption rate. Under this scenario, grazing damage is expected as pasture consumption is in excess of pasture production. Grazing damage only stops at points where pasture production exceeds consumption. Therefore, under high stocking rates the system experiences two dynamic equilibrium points. The first equilibrium point is observed early in the growing season when production lags behind consumption till pasture mass accumulates beyond the threshold level. The second equilibrium point is attained later at the end of the growing season when production is minimal and falls below consumption. In contrast, only one equilibrium point is realized under low stocking rates later towards the end of the growing season.

For the range of stocking rates tested in this model, a stocking rate of 7 TLUha^{-1} appears to be the upper limit in this agropastoral system, above which, the system's stability is likely to cave in during the growing period. At this level, production and consumption closely match from the beginning till later on in the growing period when consumption exceeds production. To operate above the critical limits, where consumption exceeds production, without affecting the stability of the system will require management strategies that take-off the grazing load till pasture production exceeds consumption. The options available in the system include destocking, supplementary feeding, and deferment with reserve pastures located within the system absorbing the grazing load. Destocking, where livestock is the main livelihood source is usually unattractive. Also, supplementary feeding, particularly with commercial supplements can be quite challenging to resource poor agropastoralists. This leaves resource poor agropastoralists with only two options of using non-conventional supplements and seeking reserve grazing within the system. The non-conventional supplements used are mainly crop residues whose production is seriously undermined by the high risk of crop failure reported in this system (Sombroek and Braun, 1980). On the other hand, use of reserve grazing that may have existed outside the system is now increasingly unavailable as these areas are currently protected as game reserves.

The stocking levels observed in the grazing areas of this study (0.09-6 TLUha^{-1}) are within the calculated optimal stocking rate. This suggests that under the equilibrium-grazing paradigm, the grazing environment in the study area should not be degraded. Evidence from the agropastoral system of southeastern Kenya point to increasing trends of degradation of the grazing areas (Mnene, 2004). Also, as most areas of pastoral and agropastoral eastern Africa, the coefficient of variation of annual rainfall in the study area exceeds 33% (Ellis, 1994). This makes the dynamics of the agropastoral system to be predominantly climate-driven and thus non-equilibrium (Ellis et al., 1993). This calls for flexible-tracking resource use strategies (Fynn and O'Connor, 2000), particularly use of variable stocking rates during the grazing cycle. Therefore, stocking levels have to be adjusted to match forage availability through continuous monitoring, a key management strategy for both equilibrium and non-equilibrium scenarios that are often non-exclusive (Briske et al., 2003).

In the studied system, the agropastoralists within their limited range tracked forage availability through seasonal grazing and use of multispecies livestock that exploit different grazing resources in space and time (Galvin et al., 2001), a resource use strategy that is in line with system dynamics. However, the agropastoralists rarely practiced destocking. Furthermore, few agropastoralists could afford to create grazing reserves and the limited farm sizes that are individually owned in this system (about 3.2 ha for 58% of the households) constrained mobility. Thus, the grazing areas were largely used throughout the year.

Faced with a limited range, inadequate pastures and the non-equilibrium scenario that compounds detection of real trends in range degradation (Hellden, 1991; Pickup et al., 1998), the agropastoralists who are largely irresponsive to adjusting livestock numbers to match available forage are likely to degrade the grazing environment. This will necessitate innovative practices to be incurporated in the system to access extra grazing. In the studied system, increasing use of secondary grazing land rights (informal grazing rights based on farm labour or ox to plough exchange) was observed and may present the only feasible alternative to accessing extra grazing and easing the grazing pressure on the diminishing grazing areas.

Conclusions

From the results of the current study, areas of concentrated drainage and sandy-clay plains are key production sites in the production system, absorbing the greatest grazing load during the dry season and wet season, respectively. The agropastoralists kept multispecies livestock that exploited a wide array of plant resources. These plant species have different phenologies and occupy different microhabitats, creating a spatial heterogeneity in food resources that attain peak production at different times. This spatial heterogeneity in food resource ensures that livestock productivity is stabilized over time. Thus, seasonal shifts in grazing across different sites, seasonality in vegetation growth and heterogeneity in resource type act to promote system stability. This suggests that resource tenure that restricts mobility and human activities that negatively affect diversity in grazing resources will undermine system stability and sustainable livestock production in the area. A stocking rate of 7 $TLUha^{-1}$ appears to be the upper limit in this agropastoral system, above which the system's stability is likely to be destabilized during the growing period. The agropastoral resource tracking strategy using multispecies livestock is in line with the non-equilibrium system dynamics that is likely predominant in the area. However, increasingly limiting farm sizes under private ownership that restrict mobility could be central to range degradation in the system.

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