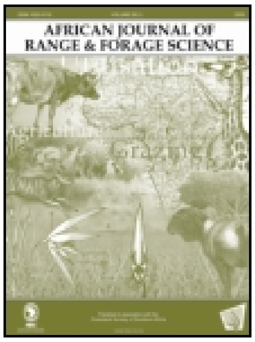

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Resilience of soils and vegetation subjected to different grazing intensities in a semi-arid rangeland of Kenya

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Abstract

The resilience of rangeland soils and vegetation to different levels of grazing is still poorly understood. A study was conducted to determine the recovery of a rangeland grazed at different intensities and allowed a two-year rest period. The following treatments were applied to 0.5 hectare plots: 0, 4, 8 and 16 heifers per hectare, hereafter referred to as CL, X, 2X and 4X respectively. At the end of the grazing period, the highest stocked treatments (2X and 4X) had lower herbage biomass, higher soil bulk density, lower soil moisture and lower herbaceous cover than the lower stocked treatments (CL and X). Drought in the rest period caused an increase in bulk density and decline in soil moisture in all the treatments. Even after the two-year rest period, the more heavily grazed treatments had higher bulk density and lower soil moisture than the more lightly grazed treatments. Similarly, the herbaceous biomass in the 2X and 4X treatments did not recover after the two-year rest period and was lower ($P<0.05$) than the CL and X treatments. At the end of the recovery period a trend of declining herbaceous cover with stocking density was still evident. The relative cover of forbs in the 4X treatments increased more than in the other treatments, while the cover of perennial grasses did not recover in the 4X treatments after the rest period. Thus, stocking above 2X produced negative soil and vegetation responses which did not recover during the two-year rest period. This study also indicated that drought can cause vegetation and soil responses similar to those of overgrazing.

Additional index words: Up to five words to be added by authors

Introduction

Studies assessing the recovery of a rangeland subjected to different levels of grazing pressure have rarely been carried out on Kenyan rangelands. The ability of a rangeland to recover to its former soil and vegetation conditions after drought and grazing is a reflection of its resilience. In a recent definition of rangeland degradation by Abel & Blaike (1990), an area is considered effectively degraded if the loss of production is beyond the bounds of resilience. This differs from the conventional approach where a change in composition from palatable to less palatable species and an increase in bare ground constitute degradation. In this paper, the new approach of Abel & Blaike (1990) was used to test the resilience of a semi-arid rangeland in Kenya to different grazing intensities.

Recently, conventional determination of carrying capacity and range condition has been extensively criticized (Behnke & Scoones 1990; Behnke *et al.* 1993). It is argued that in environments subject to highly variable in rainfall, droughts and fires, changes in vegetation are not entirely due to grazing pressure (Ellis & Swift 1988). A deterministic successional model as elucidated by Clements (1916) and adapted in the notions of carrying capacity and range condition by range scientists such as Dyksterhius (1949), Stoddart *et al.* (1975) and Herlocker (1993) may be inappropriate when applied to semi-arid African drylands (Sandford 1983).

Critics rightfully point out that the recommended stocking rates are grossly ignored by pastoralists and are often unrealistic given their production goals and environmental constraints (Bartels *et al.* 1990). However, scenes of denuded areas and dying livestock during droughts, reinforce the common belief that rangelands are overwhelmingly overstocked. Often, areas judged by range technicians to be in poor condition frequently improve dramatically after pastoralists have moved out or after good rains. The same areas previously judged to be in poor condition will often support stocking densities several times that recommended for a long time.

A debate on how to characterize degradation in African rangelands in place of the conventional model continues among range scientists. However, the state-and-transition model of Westoby *et al.* (1989) seems to be steadily gaining acceptance as a substitute to the conventional approach. A complement to this model is the concept of thresholds between states of degradation. Two important thresholds for semi-arid regions are identified. The first is that between a grassland and a woodland and the second, between a stable and unstable soil (Friedel 1991).

The resilience of a range site to climatic and grazing effects could be used as the basis to characterize degradation. Rangeland resilience is still a poorly understood and inadequately researched phenomenon. The need for research and a clearer understanding of dryland resilience was highlighted by the Rio World Summit on the Environment (Williams & Ballings 1993).

In this study, the effects of grazing intensity and a subsequent period of rest on the resilience of soils and vegetation of a semi-arid rangeland were assessed. Failure of the soils and vegetation to recover during the period was used as a strong indication of rangeland degradation. However, a longer study would have to be conducted to reach a definitive conclusion about long-term degradation.

Study area

The study was conducted at the National Range Research Center

(N.R.R.C.) in Kiboko, Kenya. The centre is approximately 180 km south-east of Nairobi on the Mombasa-Nairobi Highway (Figure 1). The vegetation, soils and climate are comparable to the adjacent extensive Maasai grazing lands of Kajiado. The area receives bimodal rainfall, with long rains between March and May, and the short rains between October and December. The soils are deep, reddish-brown ferrasols, and the relief is very gently undulating. The soils are sandy clay loams consisting of 70% sand, 25% clay and 5% silt (Michieka & Van der Pouw 1977).

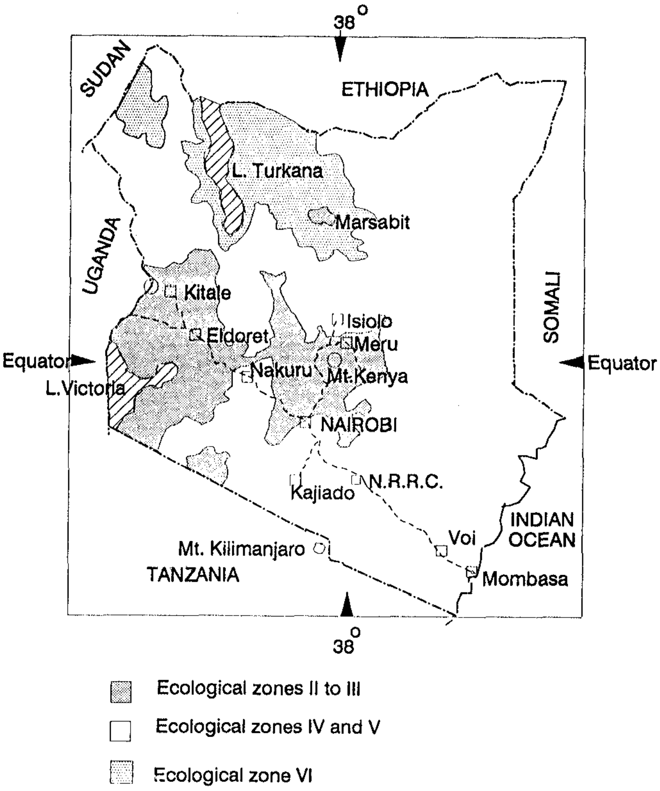

Figure 1 Sketch map of Kenya showing the location of the National Range Research Centre (N.R.R.C.).

The grazing treatments were imposed in 1992 and 1993, and this period is hereafter referred to as the grazing phase. The assessment of recovery was done in 1995 after a two-year rest period. Towards the end of the grazing phase in 1993 the long rains totally failed, marking the beginning of a drought (Figure 2). The short rains of 1993, the short dry-season rains of 1994 and the long rains of 1994 were all below average. The short rains of 1994 were above average, while the short dry-season rains of 1995 were average. Thus, in the two-year rest period only two seasons out of the six received successful rains. The years 1993 and 1995 received rainfall amounts which were below the long term average of 600 mm. A drought is considered to have occurred when rainfall for the season is inadequate for rangeland plant establishment. Musembi (1986) reviewed meteorological data from Makindu weather station, which is situated 15 km from the study site, and found a total of eight drought crisis events between 1926 and 1985. A drought crisis occurs when rains fail for three consecutive seasons. Since 1985 there has not been a drought in the region until that commencing 1993. The drought resulted in a loss of body condition of livestock on the surrounding Maasai ranches and a general movement of herds to better pastures and around permanent water points (Mworia, unpublished data).

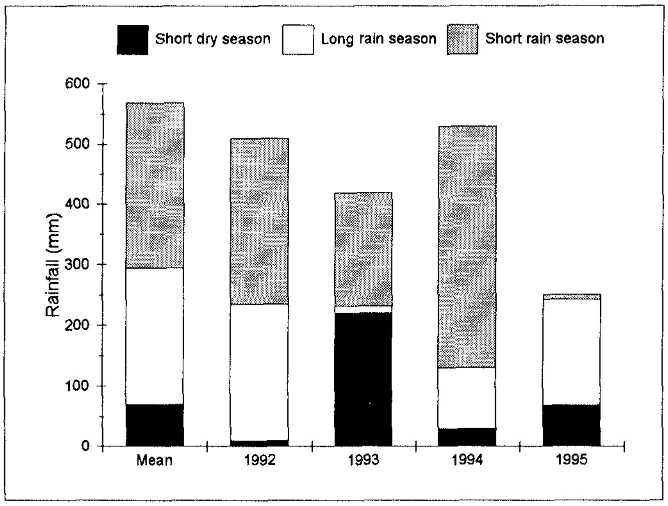

Figure 2 Rainfall recorded at the study site.

The N.R.R.C. is classified to be in Ecological Zone V which physiognomically is described as a thorn-bushland and thicket (Pratt & Gwyne 1977). The dominant woody species are *Acacia senegal*, *Acacia mellifera*, *Grewia villosa*, *Cordia ovata* and *Balanites aegyptiaca*. The dominant grass species are *Digitaria macroblephara*, *Chloris roxburghiana*, *Eragrostis superba* and *Bothriochloa insculpta*. Forbs include *Hermannia alhiensis*, *Cassia mimosoides* and *Commelina benghalensis* (Michieka & Van der Pouw 1977; Hatch *et al* 1984).

Procedure

Design and treatments

Two plots each measuring 2 ha and situated 80 m apart were demarcated (Figure 3). Each of the plots was sub-divided in four sub-plots using fencing wire. The grazing treatments were allocated randomly to each of the sub-plots. The grazing treatments were applied in 1992 and 1993. The treatments were four levels of grazing intensity namely: 0, 4, 8 and 16 heifers per hectare, hereafter referred to as CL, X, 2X, and 4X respectively.

Figure 3 Layout of experimental plots.

Data were collected before the grazing treatments (1992), immediately after the grazing treatments (1993), and after a two-year recovery period (1995).

The recommended stocking rate for the zone is 3.5 – 5.5 ha LSU^{-1} (Jaetzold & Schimdt 1983). The plots were stocked at three to twelve times the recommended rates. The adjacent communal Maasai grazing lands are almost always stocked at above the recommended rates (Gok 1988; Mworia unpublished data).

Data collection

A total of 20 soil samples per treatment were taken to determine bulk density of soils using the core method (Black 1986). Soil moisture was determined using the gravimetric method (Black 1986). A total of 20 samples per treatment, at the depth of 50 mm were collected at each of the three sampling dates. Sampling for soil moisture was also done at the depths of 150 mm and 300 mm during the recovery phase and the data were analysed separately.

The line-intercept method (Canfield 1941) was used to determine vegetative cover. For each treatment a transect measuring 50 m was used in each replicate, thus making 100 m per treatment. Herbage biomass was determined by clipping 20 samples per treatment. Samples were clipped to a 20 mm stubble height using a 0.5 m^2 quadrat. The samples were then oven-dried at 60°C for 48 h, and then weighed to determine dry mass.

Data analysis

Data were analysed as a 4x3 factorial in a randomized complete block design with two replications. Factor A was the four grazing treatments, viz. CL, X, 2X and 4X. Factor B was the three periods of sampling, viz. before grazing (1992), end of grazing (1993) and after a two year recovery period (1995). Treatment means were separated using Duncans multiple range test (Steele & Torrie 1981). In the analysis the sub-sampling variation was allocated to the residual for testing treatment differences. Use of sub-sampling variation to test treatment means is common in grazing studies (Mccalla *et al.* 1984; Wood & Blackburn 1984; Thurow *et al.* 1986). This is because of the expensive nature of grazing studies which make extensive replication difficult.

Results and discussion

Soil bulk density

Surface soil compaction influences the hydrologic condition by affecting the amount of water infiltration and runoff. Soil compaction affects productivity through its influence on conditions for root growth and establishment such as aeration and seedling emergence (Hillel 1982). Other research at this site showed that during the grazing phase high soil bulk density was correlated to high soil loss and low water infiltration (Mworia 1994).

Grazing caused an apparent increase in bulk density at the end of grazing in 1993 over the initial levels in 1992 (Table 1). Bulk density increased with increasing stocking density. The increase was significant ($P<0.05$) at the grazing level of 2X and above. The three lowest stocked treatments (CL, X and 2X) had lower ($P<0.1$) bulk density than the highest stocked treatment (4X). It was therefore only the 4X treatment that did not recover from grazing during the rest period.

After the two-year rest period bulk density apparently increased in all the treatments (Table 1). The increase can be attributed to the decline in soil moisture as result of the drought. The general increase in bulk density in all treatments between 1993 and 1995 shows that drought conditions can produce soil physical responses similar to those caused by overgrazing.

Soil moisture

Soil moisture strongly influences the energy balance between the earth and atmosphere, consequently affecting local soil and air temperature balance. This in turn influences potential evapotranspiration (Williams and Balling, 1993). Grazing affects soil moisture by modifying vegetative cover and soil physical characteristics. The soil moisture is also influenced by climatic events such as droughts, and other events which leave the soil exposed such as fires.

Table 1 Soil bulk density (0–50 mm) across sampling dates and treatments (BGR = before grazing, EGR = end of grazing, REC = recovery). Refer to the text for a description of the treatments. Means in the same column marked with different letters differ significantly ($P<0.1$)

Treatment	Period of sampling		
	BGR (1992)	EGR (1993)	REC (1995)
CL	$^{a}1.05$	$^{a}1.09$	$^{a}1.25$
X	$^{a}1.01$	$^{a}1.12$	$^{a}1.25$
2X	$^{a}1.08$	$^{b}1.24$	$^{a}1.26$
4X	$^{a}1.09$	$^{b}1.26$	$^{b}1.31$

At the beginning of the study in 1992 soil moisture was high in all four treatments due to the successful short rains (Figure 2). At the end of the grazing treatments in 1993, soil moisture was lower in the two treatments with the highest stocking density (Table 2). This was probably caused by declining vegetative cover and changes in the physical characteristics of the soil surface.

Table 2 Soil moisture (%) at varying depths by treatment and sampling date (BGR = before grazing, EGR = end of grazing). Refer to the text for a description of the treatments. Means in the same column marked with different letters differ significantly ($P<0.05$)

Treatment	BGR 1992	EGR 1993	Recovery 1995		
	50 mm	50 mm	50 mm	150 mm	300 mm
CL	$^{a}8.7$	$^{a}2.5$	$^{a}1.43$	$^{a}2.67$	$^{a}4.22$
X	$^{a}8.4$	$^{a}2.4$	$^{ab}1.49$	$^{a}2.33$	$^{b}3.19$
2X	$^{a}8.1$	$^{b}2.3$	$^{cb}1.66$	$^{a}2.81$	$^{ab}3.67$
4X	$^{a}8.6$	$^{b}1.9$	$^{c}1.75$	$^{a}2.77$	$^{ab}3.71$

By the end of the recovery period, soil moisture had declined in all treatments relative to the end of grazing. The decline in moisture over time is attributed to drought conditions. At the end of the recovery period soil moisture at the 50 mm depth was lowest in the control and highest in the 4X treatment. The trend is a reversal of the one observed at the end of the grazing treatments in 1993. This trend is probably caused by declining herbaceous biomass with increasing stocking densities (Table 3) and thus declining moisture utilization. As a result more water penetrates deeper into the soil after precipitation events in the plots with less herbaceous cover. Soil moisture at the 150 mm and 300 mm depth in the 4X treatment appeared to be slightly higher than in the 2X treatment, but this difference was not significant. With continued overstocking this difference may become pronounced. This tends to support the moisture-based concept of shrub invasion to grasslands (Harrington *et al* 1984; Stuart-Hill & Tainton 1989; Skarpe 1990). In the model, the destruction of the herbaceous layer during heavy grazing makes more moisture available to shrubs, eventually resulting in an increase in the woody vegetation.

These results show that the effects of stocking density on soil moisture are superimposed on those of drought and rainfall. Both stocking density and rainfall regime affect the vegetation structure of the site through their effect on soil moisture.

Table 3 Standing crop (t ha^{-1}) before the grazing phase and after two years recovery period (BGR = before grazing, EGR = end of grazing, REC = recovery). Refer to the text for a description of the treatments. Means in the same column marked with different letters differ significantly ($P < 0.05$)

Treatment	BGR (1992)	EGR (1993)	REC (1995)
CL	^{a}3.0	^{a}4.2	^{a}2.92
X	^{a}3.0	^{b}2.1	^{a}2.52
2X	^{a}3.1	^{c}1.2	^{b}1.83
4X	^{a}2.9	^{d}0.4	^{b}1.52

Herbage biomass

Standing crop declined with increasing grazing intensity and the highest grazing treatments (2X and 4X) did not recover after a two-year rest period (Table 3). During the recovery phase herbage biomass in CL declined, while in the grazed plots it increased to different degrees. The 4X plots showed the highest increase in herbaceous biomass during the recovery period. The increase in herbage biomass in the plots previously subjected to grazing can be attributed to rains stimulating higher growth in the previously defoliated plants. Plants in the control responded only to drought during the rest period and thus declined. Grazed plots were affected by drought and grazing. Grazing affected standing crop positively but only to the extent possible under drought conditions.

The reduced production in the 2X and 4X plots compared to CL and X can not be ascribed to intensive defoliation alone. It can rather be attributed to a combination of defoliation and the effects of soil compaction as a result of animal trampling and disturbance. The results contradict those found by Potter & Said (1986) who reported that intensive defoliation of grasses in another semi-arid area of Kenya did not lower production in subsequent seasons. However, Potter & Said (1986) used only hand-clipping to simulate grazing treatments. Thus the negative impact of animal trampling on the soil physical conditions was excluded from their experiment. The difference in the results between their experiment and ours brings to question the validity of carrying capacity estimates derived from hand clipping experiments alone. This is of particular importance because current carrying capacity recommendations are based on production estimates derived mainly from clipping studies.

Cover and composition

Before treatment, total cover was similar in all plots, but after both the grazing and recovery periods, cover declined with increasing grazing intensity (Table 4, Figure 4). At the end of the recovery period the cover of 4X was lower than the other previously grazed plots (X and 2X).

Herbaceous cover at the end of the recovery period had increased in all plots compared with the start of the grazing phase (Figure 4). This can be attributed to lack of grazing in the recovery period because the grazed plots were still enclosed. However, for the CL plots, an apparent contradiction appeared. During the recovery period, biomass decreased due to drought (Table 3) but cover increased (Figure 4). This increase in cover was caused by an increase in low-spreading forbs during the drought compared to other species, and lodging of tall grasses.

Differences in cover by species were produced by the grazing treatments. At the end of the recovery period the cover of forbs and annuals was largely increased in the 4X plots. Perennial grasses such as *Digitaria macroblephara*, *Eragrostis superba* and *Cenchrus ciliaris* were reduced by intensive grazing in 4X and did not recover to their pre-grazing level of 1992 (Table 4). The perennial grasses in 4X therefore provided less competition to forbs which increased in cover. Other species showed no consistent change with grazing intensity. However, some species such as *Hermannia alhiensis* greatly decreased in cover with increasing grazing intensity and increased with enclosure. *Digitaria macroblephara*, the most abundant perennial grass, was still below its pre-treatment cover after the rest period in the 4X plot.

The combination of increased forbs at the expense of perennial grasses, decreased overall cover, and high soil bulk density imply that the 4X stocking density is unsustainable. A high level of stocking similar to the 4X treatment is likely to be found in areas where the Maasai concentrate their herds around permanent water holes and areas which receive favourable rainfall. For these areas, the stocking density may be high enough to surpass the ability of the site to recover after heavy

Table 4 Relative herbaceous cover before grazing, in the middle of the grazing trial, and end of recovery period (Forbs = annuals consisting mainly of *Commelina benghalensis*, – = absent or insignificant). Refer to the text for descriptions of treatments CL, X, 2X and 4X.

	Before grazing				Mid grazing				Recovery phase			
	CL	X	2X	4X	CL	X	2X	4X	CL	X	2X	4X
Bothriochloa insculpta	3.6	3.7	4.4	2.7	3.7	5.4	4.4	3.0	8.5	5.5	8.4	6.7
Chloris roxburghiana	9.7	5.3	5.5	13.0	10.0	5.1	3.6	13.0	17.0	9.8	8.2	11.0
Digitaria macroblephara	33.0	32.0	38.0	33.0	40.0	34.0	35.0	17.0	32.0	32.0	36.0	20.0
Hermannia alhiensis	–	1.1	1.3	3.9	0.9	0.6	–	–	7.3	8.3	8.6	3.5
Solanum incanum	5.3	0.8	0.6	1.2	7.9	0.8	0.8	0.3	2.1	–	–	1.5
Eragrostis superba	1.4	2.2	2.6	4.6	1.2	3.7	1.6	3.6	1.6	2.6	3.2	2.0
Cenchrus ciliaris	0.4	5.4	1.5	1.4	1.0	4.5	1.1	0.8	–	1.7	1.1	–
Forbs	4.1	5.2	1.5	2.0	2.5	0.4	0.4	–	6.0	8.7	3.5	12.1
Bare ground	40.0	38.0	40.0	40.0	27.0	31.0	49.0	57.0	15.0	18.0	19	20.0
Total cover	60.0	62.0	60.0	60.0	73.0	69.0	51.0	43.0	85.0	82.0	81	70.0

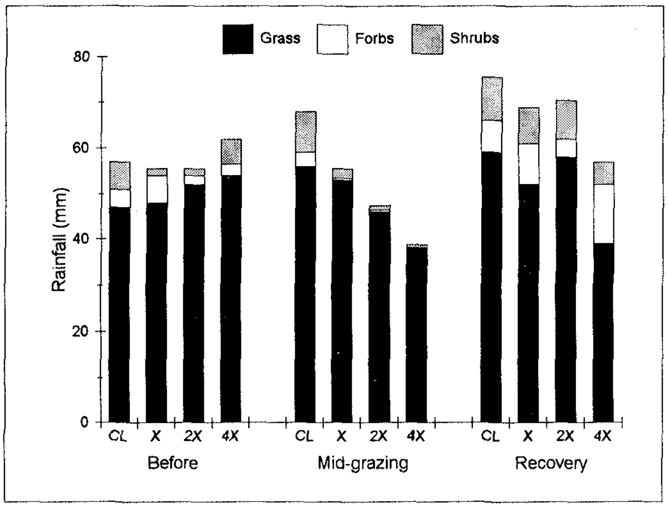

Figure 4 Herbaceous cover of all herbaceous species, perennial grasses, forbs and shrubs.

grazing events. However, this can only be tested in a long-term study.

Conclusion

The study showed that the ability of the range site to recuperate from shifts towards degradation depended mainly on two factors, viz. the level of grazing intensity and the variation in rainfall. In this study stocking densities greater than four heifers per hectare produced soil and vegetation changes that were irreversible during a two-year rest period. Drought conditions following grazing treatments produced soil and vegetation responses similar to those of overgrazing. For instance, the high soil bulk density, low soil moisture and low herbage biomass were caused by intensive grazing in the absence of drought and were also caused by drought in the absence of intensive grazing. The greater soil moisture deeper in the soil profile in the heavily grazed 4X treatment combined with low herbaceous cover and biomass could lead to a shift in the vegetation structure to a more bushed rangeland. After the rest period complete recovery in herbaceous biomass was not attained in heavily stocked plots, contrary to studies where clipping was used to simulate grazing. This can be attributed to soil disturbance during grazing and the differential responses of species to heavy grazing.

If two years is considered a sufficient recovery period, then the 4X treatments declined in production and shifted to a more degraded state. These plots had lower cover and biomass and higher bulk density than other grazed plots. The 4X treatments may imitate heavily utilized sites in the adjacent Maasai grazing areas which rarely get a rest period exceeding two years. The study shows that it is important to define the time scale and to account for drought when characterizing resilience of a rangeland site. Similarly estimates of carrying capacity based on clipping studies should be reviewed and an approach based on the determination of site potential and resilience adopted. Finally, there is need for more studies on the resilience of rangelands and climatic versus grazing effects on the environment.

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