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Rangeland characteristics of a supercritically degraded landscape in the semi-arid area of South Africa

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The objective of this study was to investigate rangeland condition in a semi-arid area with doubling erosion rates. Work was conducted using aerial photographic analysis and field investigations were conducted using 10 paired 20 x 20 m plots and 2 1 x 1 m quadrats randomly located with each plot. Degraded sites showed significant differences in soil compaction but not in soil water infiltration time. Degraded sites were characterized by absence of woody plant cover. Grass cover and litter cover were lower on degraded plots than on undegraded plots. Bare soil cover was more extensive on degraded plots than on undegraded plots. The sheet eroded plots had very low woody cover, grass cover and litter cover, low organic matter, low porosity and high soil density. Soil density on degraded sites was significantly different from undegraded sites (t test; t =3.482; df =18; p<0.05). Assessing rangeland characteristics and erosion risk in the study is part of a global management of agricultural soils that should aim at increasing productivity.

Key words: Umfolozi catchment, soil erosion, semi-arid landscapes, range-condition.

INTRODUCTION

According to Snel and Bot (1994) dry-land ecosystems are under threat from a combination of socio-economic and biophysical changes that are culminating in a downward spiral of land productivity. Land degradation has been identified as one of the key global problems today that is at the root cause of poverty, food insecurity and malnutrition (FAO, 1979; Tengberg, 2002), but is ultimately a symptom of human overpopulation. Water erosion is South Africa's most widespread soil degradation problem and affects 70% of the land (Department of Environment and Tourism, 2008).

In landscapes prone to land degradation, gullying, sedimentation, landsliding and bare soil cover, soil pedestals, crusts, exposed roots, and organ pipe erosion are often the major symptoms. The Umfolozi catchment is very vulnerable to disturbance due to slow ecological recovery, growing human populations, episodic droughts,

fire and climate change. The hardpans, organ pipe erosion, sheet erosion and gullies in the Umfolozi catchment offer many impediments to vegetation establishment by contributing a harsh substrate for the establishment and germination of seedlings. The erosion in the Umfolozi catchment may be described as supercritical being characterized by abrupt changes in productivity on the scarred and scalloped terrain. Top soil is transported to streams and this dramatic loss results in less than half the return in crop yields of normal. A total of 172.4 ha (6.3%) of land were found to be severely eroded in the study area. The purpose of this investigation is to describe the range-condition of the study area. The research hypothesis was that rangeland condition may be contributing to the increasing soil erosion in the study area.

Study area

The study area (Figure 1) lies between 28°00'00" S and

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Figure 1. Present study area situated about 10 km northeast of St Paul Mission near Nqutu in central KwaZulu-Natal (after Botha and Fedoroff, 1995).

28°10'00" S; 30° 37'00" E and 30°55'00"E), 28 km southwest of Vryheid town in central KwaZulu-Natal province. The study area and the adjacent areas have been described by Rienks et al. (2000). The surface rock is dominated by the complex Masotcheni Formation colluvial sediments and associated palaeosols. The surface lithology is defined by a stepped sandstone bedrock floor sloping at 4 - 12° with the flanking spurs and concave rocky hillslope. The colluvium within the Permian Vryheid Formation is underlain by sandstone that is exposed by sheet erosion. Other rock formations underlying the colluvium include mica, siltstone and carbonaceous shale (Rienks et al., 2000). The area is drained by Mvunyana River that feeds into the White Umfolozi River and the ultimate discharge is easterly into the Indian Ocean (Figure 1).

Land use in the Umfolozi catchment is predominantly dryland agriculture that combines rain fed agriculture and communal livestock grazing. Mondlo Communal Land in which the study area gets an average rainfall of 400 - 500 mm a year. Most of the soils are sandy. Due to a lack of ground cover, water runoff is a problem and many gullies have formed due to the soft erodible nature of the soils. Surface instability due to hardpans is a key problem that contributes to more sheet erosion. Detachment and transportation of soil particles downslope in suspension as run-off flows concentrate in channels and estuary. Rills and gullies form and expand as soil loss progresses.

Deep gullies, locally termed 'dongas', are a characteristic geomorphic feature of the hilly topography of central KwaZulu-Natal province in eastern South Africa, and pose severe constraints on the agricultural use of land by rendering much of the farmland inaccessible (Rienks et al., 2000). The landscape is scarred into badlands by hardpans, organ pipe erosion and sheet erosion. The study area encompassed both the badlands and areas in good range-condition. The Global Positioning sites (GPS sites) are given in Table 1.

The badlands are characterized by a stepped relief that may be construed as a sequence of the erosional phases. Large expanses of the land are being lowered by pediplanation and lowered and then dissected. The long duration of erosion has allowed for the incision of landscapes by deep weathering and transportation of sediment. The erosion is widespread and increasing, threatening the remaining productive landscapes, infrastructure and wiping away of livelihood options necessary to eke a living.

MATERIALS AND METHODS

Measurements of the extent of erosion on panchromatic aerial photography 2830 BB1 Nondweni 1982 taken at a scale of 1:10 000 by the Air Survey of Company of Africa Limited were done with the aid of a 4.0 x 5.0 cm plastic template grid with 0.5 x 0.5 mm divisions with each small grid covering 2500 m^2 on the ground. A

Table 1. Occurrence of the eroded land in the major land classes of the study area.

Land class	Total land area (ha)	Percent of land area (%)	Eroded land (ha)
Settlement	650	25	241.3
Cultivation	680	25	5.8
Grazing land	1360	50	142.3
Total	2720	100	172.4

total of 74 points on aerial photos were examined for presence/ absence of soil erosion with the aid of a grided plastic. The grided transparent template was employed to determine the frequency and distribution of sheet erosion in 0.5 x 0.5 mm grid cells. The delimited sheet eroded areas were transferred from the aerial photo to a Surveyor General's 1: 50 000 topographical map using physical features for mapping purposes. The 74 randomly selected points on the aerial photo covered variations in the extent of land degradation. The sheet erosion was measured in the major land classes that include settlement, grazing and cultivated areas on the aerial photo. Observations on 74 0.5 x 0.5 cm grid covered 6% of the study area.

Range condition study

The data were divided into two groups that include the control and test sites to test the effects of anthropogenic stressors. The control comprised areas identified as having negligible soil erosion as seen on aerial photo and that on the ground these sites were characterized by an absence of rills and gullies and those sites had well pronounced plant cover with negligible bare soil cover. A site comprised paired plots that include test (degraded) plots and control (undegraded) plots. The test sites exhibited poor plant cover, pronounced bare soil cover, rills and gullies on aerial photo and ground. The number of sampling locations was limited to 10 sites. All the 10 sites were randomly selected using the random number tables. Each plot measured 20 by 20 m in which 2 1 m x 1 m quadrats were randomly located to study groundcovers. The variables assessed in each quadrat include woody cover, grass cover, grass tuft density, woody plant density, woody plant girth, woody plant height, bare soil cover, litter cover, exposed root density, woody plant fire damage, woody plant drought damage, woody plant insect damage and woody plant animal damage. In the 20 x 20 m plot the following were assessed: woody plant density, woody plant girth, woody plant height, exposed roots, woody plant fire damage, woody plant drought damage, woody plant insect damage and woody plant animal damage. In addition, soil factors included soil compaction and soil water infiltration. Range condition evaluations were done in the dry season between 10th October 2008 and 1st November 2008.

A single infiltration ring measuring 10.5 cm in diameter, length 19.8 cm and a volume of 65.94 cm^3 was used to measure time taken by a falling head of water of 700 ml water to infiltrate the soil at 10 sites, on each of the 20 plots during the summer of 2008. Mean infiltration rate was calculated on each occasion. The water infiltration time in seconds was used as an index of water percolation time. The infiltration test was used to quantify the ability of water to move into and through a soil. Because of the great number of factors which can affect the flow of water through soils, it was used on a relative basis. The results from that particular set of tests are then compared to each other. Native plants influence infiltration changes through root spread. To test water infiltration time in the selected plots a level location was sought to test water infiltration rate into the soil. A site with gravel on stony ground was difficult or impossible to test water infiltration rate because of

difficulties in sinking the cylinder into the soil. A heavy lawn sod (e.g. *Cynodon dactylon* and *Hyparrhenia* sp) created similar difficulties because of the dense mat of roots. Work was conducted around living plants taking care to expose bare soil by removing any leaf litter. The soils were little disturbed wherever possible during the water infiltration tests. The cylinder was sunk into the soil approximately five to seven centimeters to create a tight seal between the bottom of the cylinder and the soil. A light iron hammer was used on a placed wooden board on top of the cylinder when hammering to keep from denting its top. The cylinder was hammered in circles around the top to keep the cylinder perpendicular with the soil surface. During the test, if water leaked out the bottoms and sides of the cylinder, tests would be repeated. The time water took to infiltrate the soils was recorded in minutes. If the soil surface was uneven inside the ring, the time in minutes was observed until half of the surface was exposed and just glistening. Timing was stopped when the surface was just glistening.

Estimates of soil compaction were obtained in the randomly selected points for sampling quadrats using a penetrometer. A steel rod freely housed in a cylindrical pipe would slide from a permanently marked position above its housing to penetrate the ground. The depth in centimeters that a steel rod penetrated the ground defines the compaction of the soil, which is taken to be the stability of soil aggregates as a result of clay particles combining with organic matter. The soil compaction measured in centimeters was used as an index of resistance to soil penetration. Soil samples were collected outside each quadrat but within the 20 x 20 m plots.

Soil water infiltration was tested using a single infiltration ring that provided an index of infiltration. A level location was sought to give the best results by allowing the water to infiltrate evenly into the soil. The soil surface was disturbed as little as possible before setting infiltration ring. The time taken for all of the water to move into the soil with complete elimination of all puddles was recorded in seconds using a stopwatch.

A T-test was used to test the hypothesis that the means of soil compaction and soil water infiltration measured between the degraded and undegraded sites are significantly different. Stepwise multiple regression was carried out using SPSS (Nie et al., 1975). Stepwise multiple regressions identified the order and degree of contribution of the independent variables in terms of prediction of eroded land transformed percentage.

RESULTS

Human factors in the erosion of the soils in the Umfolozi catchment

The accelerated soil erosion survey on aerial photo indicated that there were some 172.4 ha of eroded land in the 2720 ha study area (Table 1). This constitutes 6.3% of the area. Of the total eroded land, 142.3 ha were in the grazing lands, with 241.3 ha being in the settlement areas where people live and 5.8 ha in the cultivated land

Table 2. Location of sample plots.

| Sites	Longitude	Latitude	Elevation (m)	Sites	Longitude	Latitude	Elevation (m)
1	30°46'35"	S27°59'59"	1211	12	30°42'37"	28°02'58"	1132
2	30°46'35"	27°59'59"	1214	13	30°42'37"	28°0258"	1136
3	30°46'35"	27°59'52"	1214	14	30°42'37"	28°02'58"	1136
4	30°46'35"	28°08'00"	1216	15	30°42'08"	28°04'22"	1206
5	30°46'39"	27°59'52"	1210	16	30°42'07"	28°04'22"	1203
6	30°46'40"	27°52'53"	1210	17	30°42'06"	28°04'22"	1206
7	30°46'40"	27°59'52"	1209	18	30°41'54"	28'°04'14"	1241
8	30°42'43"	28°02'54"	1121	19	30°41'54"	28°04'13"	1247
9	30°42'42"	28°02'54"	1123	20	30°41'55"	28°04'30"	1250
10	30°42'53"	28°02'55"	1131	21	30°41'53'	28°04'13"	1250
11	30°42'42"	28°02'56"	1129				
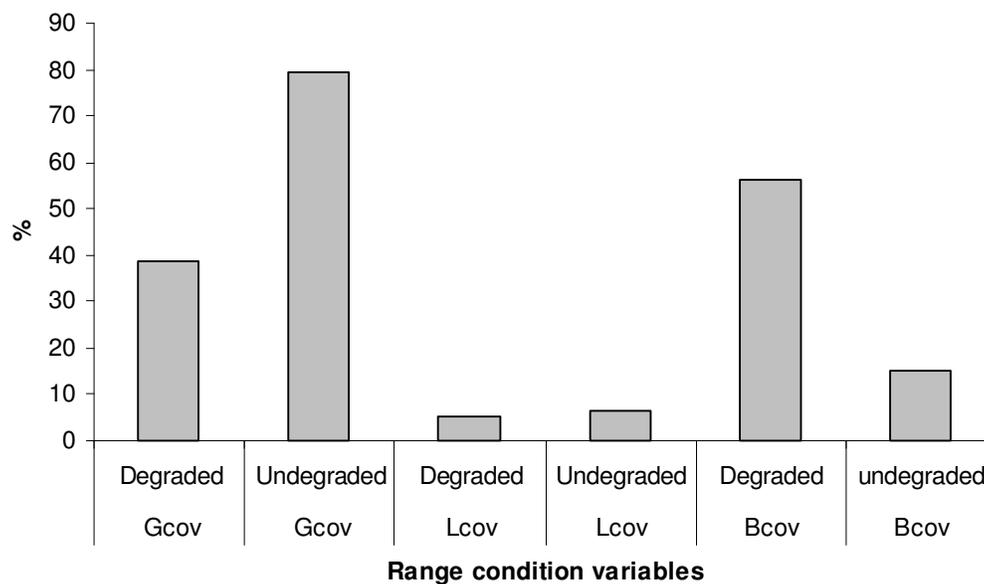
Figure 2. Mean grass cover (%), litter cover (%) and bare soil cover (%) estimated in the randomly selected plots using 1 m^2 metal frame quadrats on degraded and undegraded plots in the Umfolozi catchment (Gcov = grass cover, Lcov = litter cover, Bcov = bare soil cover).

(Table 1). About 25% of the settlement area and 25% of the cultivated areas were eroded, whereas 50% of the grazing lands were eroded (Table 1). There is much erosion in the settlement areas (Table 2).

Range condition assessment of the study area

Mean percentage grass cover was higher on degraded sites than on undegraded sites (Figure 2). Mean percentage litter cover was similar between degraded and undegraded sites (Figure 2). The mean percentage value of bare soil cover was higher on degraded sites than on undegraded sites (Figure 2). Grass cover, litter cover and bare soil cover percentage values were log transformed prior to t tests. Bare soil cover was significantly different (t = 4.293, df =14, p<0.05) between degraded and undegraded sites. Grass cover was also significantly different (t =3.400, df =10, p<0.05) between degraded and undegraded sites. Water infiltration time (seconds) and soil compaction (cm) tests were done on the randomly selected sites in the study area. Results show that soil compaction values were significantly different (Student T test, t=3.482, df=18, p<0.05) between degraded and undegraded plots (Figure 3, Table 3). Soil compaction values on degraded soils were 16% more than on undegraded plots (Figure 3). Undegraded areas show soil compaction values ranging from 3.4 to 6.15 cm
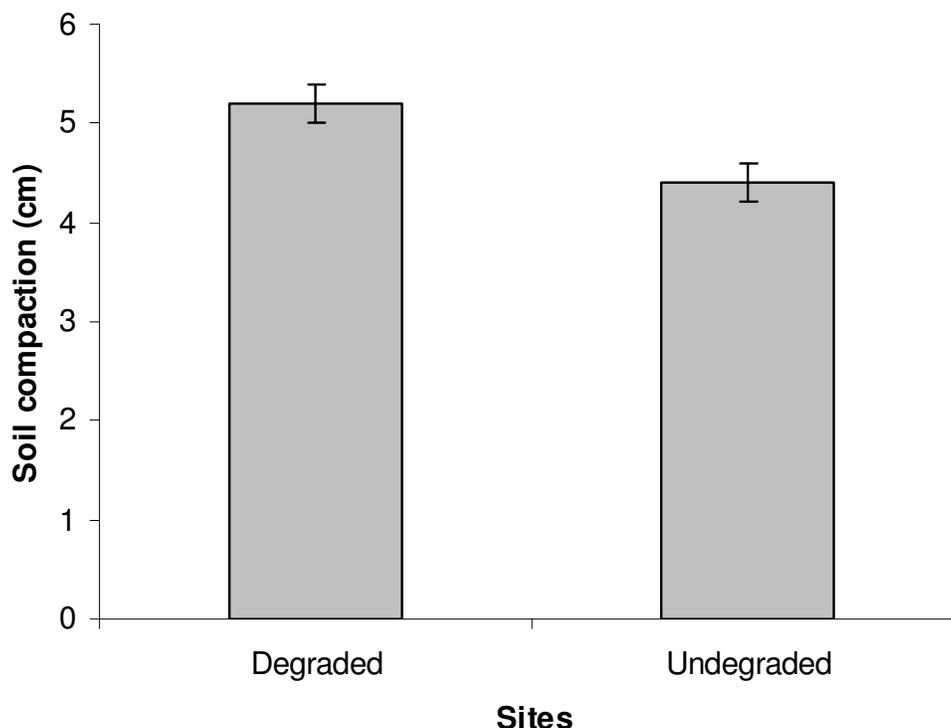
Figure 3. Soil compaction (cm) measured in degraded and undegraded plots in the Umfolozi catchment.

Table 3. T-test results of soil water infiltration time (seconds) and soil compaction (cm) measured in the degraded plots and undegraded plots in the soils of the Umfolozi catchment.

Variable	Degraded plots	Undegraded plots	t-value
Water infiltration (seconds)	175	238.9	ns
Soil compaction (cm)	5.23	4.4	*

with a mean value of 4.4 cm (Figure 3). Degraded plots show infiltration rates ranging from 3.5 to 7.0 cm with a mean value of 5.23 cm (Figure 4).

Water infiltration showed no significant differences (p>0.05) between degraded and undegraded sites (Table 3). Infiltration rates may vary in response to changes in soil moisture content, porosity, bulk density, surface strength, soil mineralogy (e.g. presence of montmorillonite) and soil moisture. Values of simple r (r values for each variable separately) in the regression analysis (Table 4) are given for all the regressor variables, allowing for the fact that these factors do not act in isolation. Given the large data set (n=75), strong and significant correlations were evident for Ivy's erosion class (spatial extent of the soil erosion) and slope angle, that is the two physical factors (Table 4). Distance to water, distance to hill and distance to road appeared to play no role in the erosion process in stepwise multiple regression (Table 4). Consequently, with increases in

rangeland usage, so the erosion becomes more widespread. Stepwise multiple regression (Table 4) identified the order and degree of contribution of the five independent variables in terms of prediction of eroded land percentage. Ivy's erosion class proved to be the most important factor influencing erosion, with a large and highly significant F-value and an r square of 0.142 (Table 4). Slope angle was the second variable to enter the equation, increasing the r square to 0.216 (with a very large F-value associated with the r2 change). Stepwise multiple regressions (Table 5) identified the order and degree of contribution of the five independent variables in terms of prediction of eroded land percentage. Soil compaction proved to be the most important factor influencing erosion, with a large and highly significant F-value and an r square of 0.606 (Table 5). Bare soil cover was the second variable to enter the equation, increasing the r square to 0.517 (with a very large F-value associated with the r2 change).
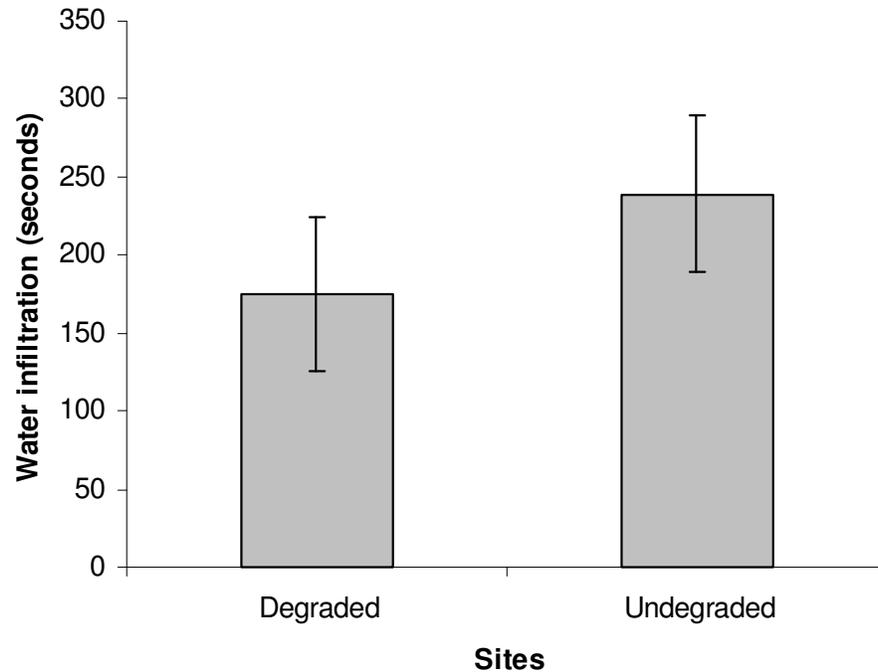
Figure 4. Water infiltration time (seconds) measured on degraded and undegraded plots in the Umfolozi catchment.

Table 4. Results of multiple regression with stepwise variable selection using plot level percent of erosion as the dependent variable and Ivy's erosion class, distance to water, distance to hill, distance to road and slope angle as predictor variables (*=P<0.05; **=P<0.005).

Predictor variable	Simple r	r square	F-value	Sig.
Ivy's erosion class	0.376	0.142	13.53	**
Distance to water			0.348	ns
Distance to hill			0.009	ns
Distance to road			0.068	ns
Slope angle	0.465	0.216	6.817	*

Table 5. Results of multiple regression with stepwise variable selection using plot level percent of erosion as the dependent variable and soil infiltration, soil compaction, grass cover, bare soil cover and litter cover as predictor variables.

Predictor variable	Simple r	r square	F-value	Sig.
Soil infiltration			1.371	ns
Soil compaction	0.779	0.606	4.105	*
Grass cover			0.072	ns
Bare soil cover	0.719	0.517	20.850	**
Litter cover			0.058	ns

DISCUSSION

The highest level of erosion in a land class (Table 1) was recorded in the human settled areas and this was followed by the grazing areas and lastly cultivated areas.

A total of 172.0 ha (6.3%) of land were found to be severely eroded in the study area. Field observations showed some gullies extending into the cropped areas. The soils of the Umfolozi catchment exhibit severe forms sheet erosion that is characterized by extensive areas of

bare soil cover and gullies. The sheet eroded plots have very low woody cover, grass cover and litter cover. Woody cover, grass cover and litter cover are important environmental protective forces that act against the energy of raindrops. Many previous researchers (Botha, 1994, 1995; Watson, 1993, 1996a, 1996b) agree that the causes of land degradation are mainly anthropogenic and agriculture related. The major causes include: land clearance, deforestation, and agricultural depletion of soil nutrients, burning and absence of soil conservation measures.

The major problems which the households experience in their agricultural activities are erosion and a prolonged dry season which reduce the level of crop production (Watson, 1993). The livestock owned include the cattle, goats and sheep. Grazing areas are not fenced. The high rates of soil erosion have led to the intervention of the Department of Agriculture with contingency measures. The assistance provided by the Department of Agriculture include the testing of soil in the crop fields at a low cost (R40-00), recommendation on fertilizers to be used and training of community members on the preparation of crop fields and erosion control. The erosion is increasing and even doubling up and as part of the erosion risk assessment an understating of the present range-condition is necessary. Values of simple r (r values for each variable separately) in the regression analysis are given for all the regressor variables, allowing for the fact that these factors do not act in isolation. Strong and significant correlations were evident for plot erosion and soil compaction and bare soil cover. Soil water infiltration, grass cover and litter cover appeared to play no role in erosion process in stepwise multiple regression (Table 5). Consequently, with increases in rangeland usage, so the erosion becomes more widespread.

Distance to water, distance to hill and distance to road appeared to play no role in the erosion process in stepwise multiple regression. Consequently, with increases in rangeland usage, so the erosion becomes more widespread. Clearly, the human factors and physical factors stand out as being a greater influence on erosion in this analysis. Stepwise multiple regression identified the order and degree of contribution of the independent variables in terms of prediction of eroded land percentage and seedling density. When erosion is used as the dependent variable, erosion class, slope angle, soil compaction and bare soil cover proved to be the most important factors influencing erosion. Clearly, the human factors and physical factors stand out as being a greater influence on erosion in this analysis.

The human factors in the Umfolozi catchment have been blamed on the loss of protective factors in the study area. Degraded sites are characterised by low cover of the sward, high bare soil cover, low litter cover, sparse plant cover, pronounced soil density, low soil organic matter and low porosity. Our results contrast with Dougill and Cox (1995a) who suggest that vegetation changes

are poor indicators of damage to resilience. In Botswana, vegetation changes reflect loss of resilience (Dougill and Cox, 1995b). Dougill and Cox (1995) further suggest that there is no evidence to suggest that grazing leads to soil degradation, and as such links between cattle and 'land degradation' should treated with care. A new perspective on interactions among climate, plants, and herbivore suggests that rangelands influenced by highly stochastic weather and grazing disturbance are degraded, not only by continuous grazing. Lavorel and Garnier (2002) point to the importance of climate in understanding rules relating to site variables to favoured plant traits. The functional relationships between these plant functional attributes and recognizable plant functional types in vegetation and the assembly and disassembly rules for the coexistence of these different plant functional types in major plant communities. Wilson et al (1984) discuss how grazing, but rather by the long-term absence of grazing. Arid rangeland plants that are grazed continuously may have lower residual biomass and ground cover, but they may also have greater production and better survival than ungrazed plants. Consequently, grazing, rather than being destructive, is necessary for proper management of arid zone pastures. non-equilibrium grazing models describe opportunistic land-use strategies in response to unpredictable disturbance (e.g., climate, fire, and grazing) and resulting changes in forage production. One really has show a change in the shape of the stocking rate and productivity relationships to demonstrate degradation in, for example, a pastoral production context but the criteria may be very different for other land use systems.

Meadows and Hoffman (2003) concluded that the most severely degraded areas in South Africa, including large areas of the former 'homeland' states, are likely to become even more susceptible under predicted climate change scenarios. In contrast, non-equilibrium rangeland systems are thought to be driven primarily by stochastic abiotic factors, notably variable rainfall, which results in highly variable and unpredictable primary production. Livestock populations are thought to have negligible feedback on the vegetation as their numbers rarely reach equilibrium with their fluctuating resource base. Recent studies suggest that most arid and semi-arid rangeland systems encompass elements of both equilibrium and non-equilibrium at different scales, and that management in the Umfolozi catchment needs to take into account temporal variability and spatial heterogeneity. Arid rangeland plants that are grazed continuously may have lower residual biomass and ground cover, but they may also have greater production and better survival than ungrazed plants. Consequently, grazing, rather than being destructive, is necessary for proper management of arid zone pastures (Oba et al., 2000). Opportunistic grazing where stocking rates are aimed at taking advantage of the growing vegetation in the wet season with a lowering of the stocking rates in the dry season could reduce pressure on the degraded landscapes in the study

area. Ellis and Swift (1988) and Briske et al. (2003) outlined the need to develop alternate paradigms on the stability of African pastoral ecosystems but such an approach requires detailed knowledge systems of rangeland condition. The range condition characteristics provide an opportunity of identifying critical rangeland constraints in the recovery of the degraded landscape.

ACKNOWLEDGEMENTS

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