ERRATA

Page 27, paragraph 1, 3rd sentence: The speculative statement "The slightly lower initial soil moisture recorded for some degradation gradients could be ascribed to higher transpiration rates of climax vegetation......." is not valid in the light of findings by Snyman (1989) who concluded that evapotranspiration of climax and sub-climax vegetation does not differ significantly. (See "Snyman, H.A. 1989. Evapotranspiration and water use efficiency of different grass species in the central Orange Free State. Journal of the Grassland Society of Southern Africa, 6: 146-151").

Page 75, paragraph 1, last sentence: The phrase "and scientists alike" should be omitted.

Page 75, last sentence on page: It must, in all fairness to the range science profession in southern Africa, be added that existing scientific knowledge to alleviate the patch-overgrazing problem (i.e. controlled selective grazing and other applicable rotational grazing strategies) is generally not applied by the land owners in order to halt the retrogression.

SOME IMPORTANT CONCEPTS AND PERSPECTIVES IN RANGELAND ECOSYSTEM DYNAMICS AND THEIR SIGNIFICANCE FOR RANGELAND SCIENCE

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Thesis accepted in the Department of Plant Sciences in the Faculty of Natural Sciences of the Potchefstroom University for Christian Higher Education in partial fulfilment of the requirements for the degree Magister Scientae.

Supervisor: Prof. O.J.H. Bosch

Potchefstroom

1990

Scientific work not published is scientific work not done.

(Alley, 1987)

The ultimate goal of the range scientist should be to serve the profession so that mankind can do a superior job of managing and preserving rangeland resources.

(Wright, 1988)

"And God blessed them and told them, "Multiply and fill the earth and subdue it; you are masters of the fish and birds and all the animals"".

Genesis 1:28 (Anon, 1988)

"We abuse land because we regard it as a commodity belonging to us. When we see land as a commodity to which we belong, we may begin to use it with love and respect".

(Leopold, 1966)

ACKNOWLEDGEMENTS

Many thanks and deep appreciation to:

* God almighty who has blessed me with the opportunity and talents to complete this work

* My loving spouse for her support, encouragement and patience

* Many unknown reviewers of included and other submitted papers who have contributed to the work as well as to my personal development as scientist

* My parents and parents-in-law for their support and encouragement

* Mr. G.F. Smith for his invaluable support in many ways

* Mr. and Mrs. R. Van Niekerk - their hospitality and assistance made field work a pleasure

* Last but not least Prof. O.J.H. Bosch for financial support and useful comments. The fact that I was allowed to direct and complete the research independently is especially appreciated.

PREFACE

The principle part of this thesis consists of a selection of manuscripts submitted for publication consideration to a variety of scientific journals covering the fields of range ecology, range science and vegetation science. The manuscripts conform to author instructions as stipulated by the respective journals. The manuscripts are included as they were forwarded to the editors. Consequently stylistic irregularities occur between chapters. However, for the sake of orderliness, margins were adjusted throughout. For the same reason line-numbers were deleted from the manuscript submitted to the Journal of Range Management.

Where applicable chapters include the following subsections: Introduction, Study Area, Materials and Methods, Results, Discussion and Conclusions. An incipient introductive chapter, an overall chapter addressing materials and methods, a final discussion and an all inclusive reference list have also been included.

In the introductive chapter the initial aims of the study are stated. However, a variety of concepts and perspectives evolved as the data were interpretated. The end result is a selection of apparently divergent papers. Yet all research papers included in the thesis originated from the same study.

Only a portion of the actual data collected for, amongst others, method evaluations and application adjustments, habitat condition assessment trials (e.g. using pin penetrometer) and vegetation trend assessments are presented in the thesis. Since the backbone of the thesis is a selection of submitted manuscripts, the remaining data which do not lead to any significant or substantiable conclusions were not included.

The author makes no apology for the often strong emphasis on habitat attributes, the somewhat unique viewpoints or the sometimes philosophical tendency in the final discussion.

ABSTRACT

Research was initiated to evaluate the influence of mismanagement on the range habitat and to study habitat and vegetation interactions during range succession and retrogression processes in the climatic climax grasslands of southern Africa. Simultaneously the impact of patch-overgrazing on range vegetation and habitat attributes was assessed and patch-dynamics were monitored.

In seriatim some of the main findings and contributions to range science are as follows:

* Substantial habitat degradation occurs concomitant with vegetation retrogression in overgrazed areas. Rainfall effectivity reductions of more than 50% are not uncommon in severely overgrazed areas.

* Monitoring of vegetation attributes will give no timely warning of habitat retrogression due to a time-lag between habitat retrogression and vegetation retrogression.

* A descriptive range ecosystem retrogression model, which illustrates the biotic and abiotic interactions and ecosystem degradation dynamics associated with rangeland retrogression processes, is presented.

* Patches in poor condition expand at the expense of less degraded patches in years of below-average rainfall.

* Patch-selective overgrazing has a detrimental effect on the stability of semi-arid rangelands. The resilience of range vegetation to unfavourable climatic conditions is adversely affected where patch-overgrazing occurs.

* Results indicate that semi-arid rangelands which have retrogressed beyond a threshold of drought resilience can not rest-recover.

* Urgent research is needed to devise management strategies to reduce patch-overgrazing in semi-arid and arid rangelands. If present levels of patch-overgrazing are not reduced substantially, the continued retrogression of these rangelands will not be halted.

* Range vegetation succession towards a more desirable species composition, basal cover and phytomass production could be directed through habitat improvements.

* Habitat condition governs rangeland vegetation trends.

* The range habitat is more sensitive to mismanagement than the vegetation. Consequently habitat retrogression precedes vegetation retrogression.

* Management strategies should be evaluated firstly according to their ability to preserve or improve the range habitat.

* Habitat condition has to be assessed simultaneously with other relevant rangeland condition attributes to ensure that range condition assessments are a true reflection of the actual condition of the range.

* A technique for objective habitat condition assessments in rangelands is presented.

* The necessity of a much more habitat orientated approach in range science and management is illustrated.

* A rainfall effectivity orientated environmental management philosophy is regarded as the key to successful natural resource management and preservation.

UITTREKSEL

Die effek van wanbestuur op die habitat asook interaksies tussen die habitat en die plantegroei tydens weiveldherstel en -retrogressie is in die klimaatsklimaksgrasveld van suidelike Afrika bestudeer. Tesame hiermee is kol-dinamika bestudeer en die impak van kol-oorbenutting op die weiveldplantegroei en -habitat bepaal.

Die belangrikste bevindinge wat 'n bydrae lewer tot weiveldekologie as vakwetenskap, is die volgende:

* Omvangryke habitatdegradasie vind plaas tydens plante=groeiretrogressie in weiveld. Dit gee daartoe aanleiding dat afnames in reënvaleffektiwiteit van meer as 50% nie ongewoon is in ernstig oorbenutte gebiede nie.

* Monitering van slegs plantegroeitendense gee nie 'n betroubare aanduiding van veranderinge in habitattoestand nie aangesien die habitat vinniger op oorbenutting reageer as die plantegroei.

* 'n Beskrywende weiveldretrogressiemodel wat biotiese en abiotiese interaksies tydens weiveldretrogressie illustreer, word aangebied.

* Kolle in 'n swak toestand vergroot ten koste van aan=grensende kolle in beter toestand selfs tydens matige droogtes.

* Kol-oorbenutting het 'n negatiewe effek op die stabiliteit van semi-ariede weivelde. Plantegroei van oorbenutte areas is selfs nie teen minder ernstige droogtes bestand nie.

* Langtermyn-rus is nie voldoende om ernstig oorbenutte semi-ariede weiveld effektief te laat herstel nie.

* Navorsing is dringend noodsaaklik om bestuurmaatreëls daar te stel om kol-oorbenutting te verhoed. Indien die huidige vlakke van kol-oorbenutting nie drasties verlaag word nie, sal die retrogressie van semi-ariede en ariede streke voortduur.

* Weiveldherstel kan bewerkstellig word deur habitattoestande te verbeter.

* Die habitat is sensitiewer vir wanbestuur as die plantegroei. Habitatdegradasie gaan dus plantegroeiretrogressie vooraf.

* Die sukses van weiveldbestuur moet eerstens beoordeel word volgens die mate waartoe daarin geslaag word om habitattoestande te handhaaf of te verbeter.

* Die toestand van die habitat moet bepaal word tesame met ander relevante aspekte wanneer weiveldtoestand bepaal word. Dit sal verseker dat die toestandbepaling 'n betroubare weergawe is van die werklike toestand van die weiveld.

* 'n Metode vir objektiewe habitattoestandbepalings in wei= velde word aangebied.

* Die noodsaaklikheid om die klem in 'n groter mate op die habitat te laat val in weiveldbestuur en -navorsing word geïllustreer.

* Omgewingsbestuur moet gerig wees op reënvaleffektiwiteit om effektiewe hulpbronbestuur en -bewaring te verseker.

CONTENTS

CHAPTER 1

INTRODUCTION

INTRODUCTION

The semi-arid climatic climax grasslands of southern Africa are regarded as the most important rangeland type for stock-farming in southern Africa (Mentis & Huntley, 1982). Its continued retrogression poses an ever increasing threat to livestock production and resource conservation (Bosch, 1988). In order to understand, assess and monitor rangeland trends, and to devise management strategies for optimal utilisation concomitant with resource conservation, extensive range vegetation dynamics studies were conducted in the area (Janse van Rensburg, 1987; Bosch, 1989).

Generally, these and other rangeland dynamics studies conducted in southern Africa have focused principally on vegetation monitoring, animal husbandry and the application of vegetationally and agriculturally based principles in range management. By comparison very little, if any, research has been conducted to define range habitat dynamics, to assess the influence of management practices on the habitat, to monitor habitat changes and to evaluate the influence of habitat condition and trends on range vegetation dynamics. Subsequently research was initiated to evaluate the impact of mismanagement on the range habitat and to study habitat and vegetation interactions during range succession and retrogression processes. Habitat in the context of this study is regarded as a combination of range soil and hydrology attributes such as soil condition, soil crusting and compaction, erosion, run-off, infiltration and rainfall effectivity. These abiotic factors play important roles in the well-being of plant and animal components in rangelands. Knowledge about range habitat dynamics, vegetation and habitat interactions in rangelands and the application/consideration of relevant habitat principles and philosophies in range management may prove to be indispensable for optimal biomass production and resource conservation.

Secondly, patch-selective overgrazing was identified as an important phenomenon in range dynamics and range retrogression which merits further investigation. Subsequently habitat attributes and aspects of patch-selective overgrazing were addressed simultaneously where applicable. Livestock grazing in grassland vegetation creates a micro-pattern in which heavily grazed areas alternate with lightly grazed or ungrazed areas (Bakker *et al*., 1983; Ring *et al*., 1985). Heavily grazed areas are utilised repeatedly which results in extensively overgrazed patches (Ring *et al*., 1985). Patch-selective overgrazing is a common phenomenon in the semi-arid climatic climax grasslands of southern Africa. Unfortunately patch-selective grazing is not restricted to specific edaphic attributes, vegetation types, land types or dependent on the type of grazing animal (Personal observation). Research was initiated to assess the impact of patch-overgrazing on range vegetation and habitat, to evaluate the role of patch-selective overgrazing in rangeland retrogression and to study patch-dynamics over time.

CHAPTER 2

STUDY AREA

STUDY AREA

The research was conducted in the 600-650 mm per annum rainfall belt in the central part of the climatic climax grasslands of southern Africa (Fig. 1). The vegetation is described by Acocks (1988) as Cymbopogon-Themeda grassland. Rainfall is erratic, occurring mainly in the form of heavy thunder-showers of short duration which are restricted to the warm summer months (Anonymous, 1984). The area is underlain by shale, sandstone and mudstone. Crests and scarps occur on dolerite and sandstone with mid-slopes predominantly on mudstone and shale. The topography is undulating to flat. More than 70% of the terrain consists of pediments (Scheepers et al., 1984).

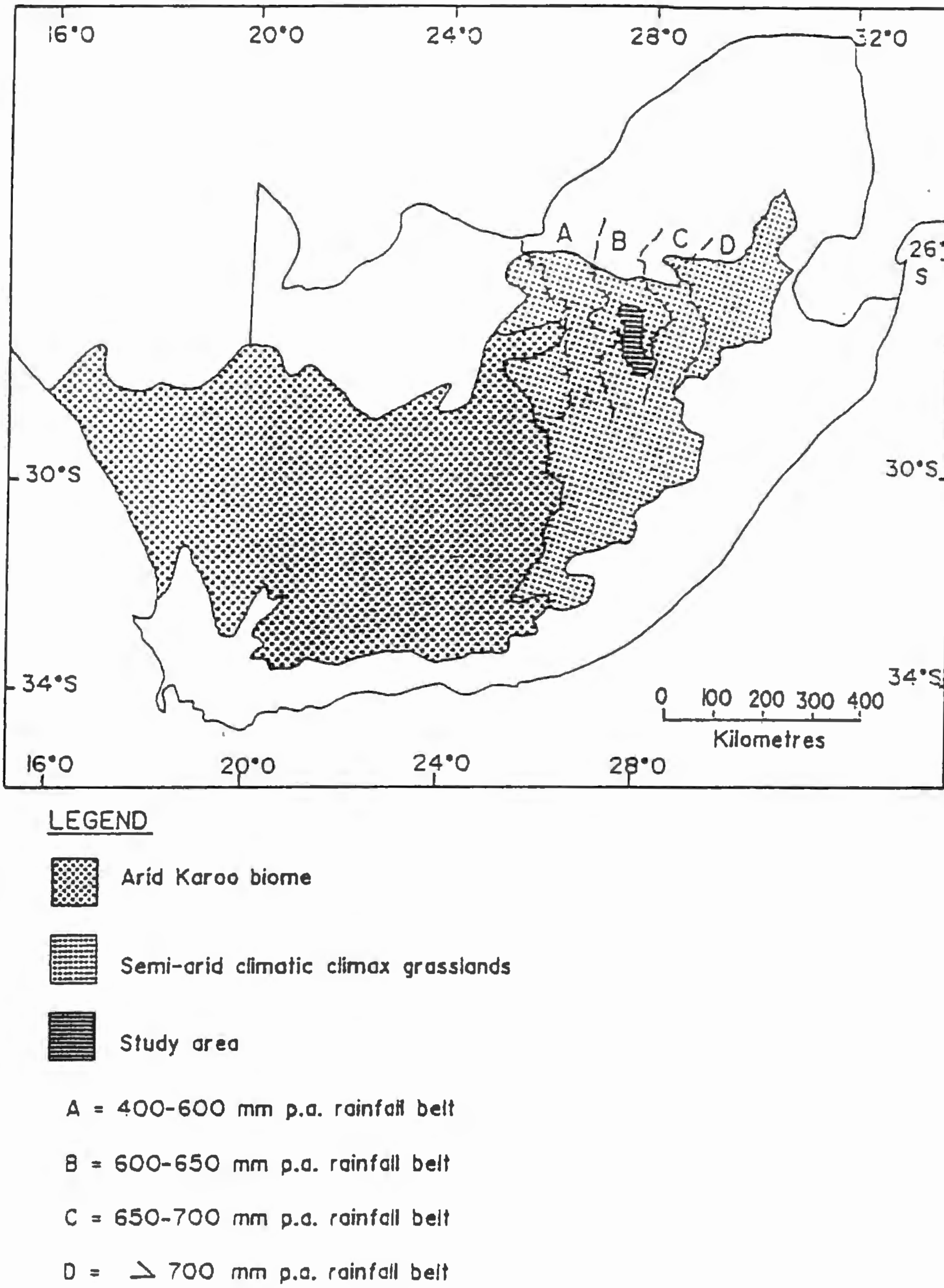

Figure 1. The study area in the 600-650 mm p.a. rainfall belt of the climatic climax grasslands of southern Africa.

CHAPTER 3

MATERIALS AND METHODS

MATERIALS AND METHODS

Six micro-scale degradation gradients, extending from patches in good range condition to severely degraded patches, were used to assess habitat degradation dynamics, habitat and vegetation interactions during range retrogression processes and to evaluate the impact of patch-selective overgrazing on the rangeland ecosystem. Habitat and vegetation data were collected as follows:

One metre wide belt transects were marked out to delineate the degradation gradients. The transects were subdivided into one square metre micro-plots. The following measurements were conducted in each micro-plot:

- Total basal cover was determined with 5x1m line transects (Canfield, 1941; Brown, 1954).

- The vegetation composition was recorded with a pin and a 100 point grid placed over each micro-plot. At each of the 100 points the pin was lowered and the nearest grass species recorded.

- Soil crust hardness was measured with a falling pin penetrometer. The pin was lifted 300mm, dropped and the depth of soil penetration recorded. This procedure was repeated twenty times per micro-plot, on a random sampling basis.

- A soil auger, 30mm in diameter, was used to extract two soil samples (approximately 300g), to a depth of 200mm. The gravimetric soil moisture content of these soil samples was established according to the method described by Hillel (1982).

- The depth of the A-horizon was determined with a soil auger.

- The degree of vegetation utilisation was subjectively assessed on a scale of 1-6, where:

U1 = no utilisation; U2 = slight utilisation; U3 = moderate utilisation; U4 = moderate severe utilisation; U5 = severe utilisation and U6 = extremely severe utilisation.

The slope, direction of run-off and other relevant micro-topographical aspects were recorded. Samples of the soil types were analysed physically and chemically.

The range condition assessment module of the PUK model for grassland dynamics (Bosch et al., 1988; Bosch et al., 1989) was used to assess the range condition of each micro-plot.

To ease interpretation of floristic changes, the recorded grass species were classified according to their ecologic status as determined by Janse van Rensburg (1987).

Vegetation cover, crust penetration, depth of A-horizon (erosion extent), range condition and soil moisture content were cross-correlated, using linear regressions, to determine the respective correlation coefficients and coefficients of variation.

To study the influence of habitat condition on vegetation trends, five disparate soil types were selected which also occur commonly in the study area. This was done to include a wide range of edaphic variation. The soils were classified according to the South African and FAO classification. The five soil types were (FAO classification in brackets): Bonheim (Luvic phaeozem), Swartland (Brunic luvisol), Avalon (Plinthic luvisol), Hutton (Rhodic ferralsol), and Glenrosa (Eutric cambisol) (Dudal, 1968; Macvicar et al., 1977).

Three 30x30m research plots were selected for each soil type and fenced off in February 1989. Each research plot was selected to include a variety of patches representing varying stages of rangeland retrogression, induced by patch-selective overgrazing. Four to ten 2x1m permanent micro-plots, depending on variations in patch sizes and condition, were established in each research plot. The micro-plots were selected in such a way that most stages of rangeland retrogression were represented. Furthermore, selected micro-plots were located in such a way that patch dynamics (e.g. fluctuations in patch-boundaries) could be monitored. A total of 116 permanent micro-plots were established on the five soil types.

Vegetation trends in the micro-plots were assessed in the following way: A line intercept method was chosen to record species basal cover in the micro-plots (Canfield, 1941; Brown, 1954). A metal frame containing 5 x 2m steel wire transects was used for vegetation surveys. The anchor holes of the metal frame correspond with pegs delineating the 2x1m micro-plots. The anchor holes and pegs in the soil ensure exact spatial resampling in subsequent vegetation surveys.

The first sampling of the permanent micro-plots was done in March 1989 (late summer). The seasonal variation of grassland cover (Morris & Müller, 1970) implies that subsequent resamplings of the micro-plots must be done at comparable stages of the growing season. Therefore resampling of the micro-plots was conducted in March 1990.

The data of 1989 and 1990 samplings were compared to assess vegetation trends after 12 months of livestock exclusion. The recorded species were classified according to their ecologic status, as adapted from Janse van Rensburg (1987), to ease interpretation of vegetation trends.

Before the importance and influence of habitat condition in rangeland dynamics and trends could be assessed, a method had to be devised to establish the degree of habitat retrogression (habitat condition) objectively. Soil wetness variations between micro-plots in a specific grazing exclosure were used as habitat condition indices. This practice can be justified by the following reasoning: The amount of moisture present in the soil at a specific site, at a given moment, is determined by a variety of biotic and abiotic factors, e.g. rainfall, temperature, radiation, air convections, topographical and soil characteristics, vegetation type and cover, evapotranspiration, soil compaction and crusting, infiltration, run-off and erosion. If the long-term average soil wetness declines at a specific site in spite of unchanged environmental inputs (precipitation, radiation, wind, temperature), it is regarded as a reduction in rainfall effectivity. Reductions in rainfall effectivity are the result of detrimental habitat changes, e.g. soil compaction and crusting, reduced infiltration and increased run-off (Stallings, 1957). Consequently, significant differences in soil wetness between sites which are subjected to similar environmental conditions and inputs over time are attributable to differences in habitat condition. Because the micro-plots in each grazing unit are subjected to identical environmental inputs, differences in soil wetness were regarded as differences in habitat condition.

Soil wetness of selected micro-plots was recorded as follows: Three soil samples were collected on 28 November 1989, 9 January 1990 and 12 March 1990 respectively at each respective micro-plot. These soil samples were extracted 150mm away from the micro-plot boundaries, on the outside, and the holes filled up carefully afterwards to ensure minimal disturbance in or around the research plots. On each occasion the three soil sampling sites were spaced evenly around the respective micro-plots. The soil samples were extracted to a depth of 200mm, using a soil auger with a 30mm diameter. It is argued that the wetness of the upper 200mm of the soil is primarily influenced by variations in rainfall effectivity whereas soil wetness at depth is increasingly influenced by the water-table, long-term annual precipitation and redistribution of subsoil moisture. The soil samples were sealed in airtight containers to prevent moisture losses due to evaporation. The respective gravimetric soil moisture contents of these soil samples were established according to the method described by Hillel (1982).

CHAPTER 4

ECOSYSTEM MODIFICATION CREATED BY PATCH-OVERGRAZING IN A SEMI-ARID GRASSLAND

Manuscript submitted for publication in "The Journal of Applied Ecology"

ECOSYSTEM MODIFICATION CREATED BY PATCH-OVERGRAZING IN A SEMI-ARID GRASSLAND

RUNNING HEADLINE: ECOSYSTEM MODIFICATION DUE TO OVERGRAZING

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SUMMARY

(1) The influence of patch-overgrazing on vegetation and habitat state of health was studied in the climatic climax grasslands of southern Africa. The research was conducted on six micro-scale degradation gradients, extending from patches in good range condition to severely degraded patches.

(2) Long-term patch-overgrazing causes reduction in high ecologic status tufted perennial grasses within overgrazed patches. As vegetation retrogression progresses, a sequential increase in lower ecologic status tufted perennial grasses, low ecologic status creeping grasses and annual and pioneer grasses of low ecologic status was recorded. Eventually xeric karroid shrubs invade the degraded patches.

(3) The average decline in basal cover, for the six micro-scale degradation gradients studied, was 90%.

(4) Substantial habitat degradation occurs concomitant with vegetation retrogression. A reduction of average soil crust penetration from 41mm to 13mm, within a distance of five metres, was recorded for a degradation gradient. Increasing topsoil losses were recorded as the vegetation deterioration advances. Most denuded patches were characterised by the absence of an A-horizon.

(5) Rainfall effectivity declines in concert with habitat and vegetation degradation. Soil samples, to determine gravimetric soil moisture content, were extracted from a degradation gradient one hour after an 18mm rainfall event occurred (thunder- shower). An average gravimetric soil moisture content of 24,2% was recorded for the micro-plot in good range condition. In contrast the average soil moisture content of the most degraded micro-plot was 12,5%.

(6) Intercorrelations of habitat factors indicated that gravimetric soil moisture content is primarily influenced by soil crusting. Basal cover reduction was principally related to increasing loss of topsoil.

(7) A descriptive ecosystem modification model was compiled which illustrates the biotic and abiotic interactions and ecosystem degradation dynamics associated with rangeland retrogression processes. The end result of these degradation processes is the creation of an unstable ecosystem with a significantly reduced rainfall effectivity.

INTRODUCTION

The semi-arid climatic climax grasslands of southern Africa are regarded as the most important rangeland type for stock-farming in southern Africa (Mentis & Huntley 1982). Its continued degradation poses an ever increasing problem for livestock production and resource conservation (Bosch 1988). This deterioration has been ascribed to injudicious management in association with periodic droughts (Roux *et al*. 1981). The extension of xeric vegetation types into more mesic types is part of the vegetation retrogression and desertification processes in southern Africa (Roux & Vorster 1983; Bosch 1989). Acocks (1988) predicts that approximately 50% of presently climatic climax grassland will consist predominantly of xeric karroid shrub vegetation by the year 2050 if current malpractices are maintained.

Apart from reports of run-off and sediment loss increases due to climatic climax grassland deterioration (Snyman, Van Rensburg & Opperman 1984; Snyman, Van Rensburg & Opperman 1985; Snyman & Van Rensburg 1986), retrogression studies have in the past focused on compositional changes occurring as vegetation deteriorates (Roberts 1984; Janse van Rensburg 1987; Acocks 1988; Bosch 1989). Consequently research was undertaken to specifically study habitat retrogression concomitant with vegetation dynamics in an attempt to evaluate the impact of overgrazing in general, and patch-overgrazing in particular, on range ecosystem retrogression.

Sheep grazing in grassland vegetation creates a micro-pattern in which heavily grazed areas alternate with lightly grazed or ungrazed patches (Bakker, de Leeuw & von Wieren 1983). In the climatic climax grasslands the mosaic consists of heterogeneous patches which are in varying states of health or range condition. Heavily utilised patches are grazed repeatedly which results in extensively overgrazed patches (Ring, Nicholson & Launchbaugh 1985). The degraded patches tend to increase in area and number as over-utilisation continues.

Patch-overgrazing is a common phenomenon in the semi-arid climatic climax grasslands of southern Africa. If vegetation retrogression and serious habitat modification occur as a result of patch-overgrazing, it would have important implications for range management. Knowledge about range habitat dynamics and application of habitat principles in range management may prove to be indispensable for optimal biomass production and range conservation.

STUDY AREA

The research was conducted in the Edenville district in the semi-arid climatic climax grasslands of southern Africa (Figure 1). The rainfall is erratic and precipitation occurs mainly in the form of heavy thunder-showers which are of short duration. The rainfall is almost totally restricted to the warm summer months (Anonymous 1984). The vegetation is described by Acocks (1988) as Cymbopogon-Themeda grassland. The area is underlain by shale, sandstone and mudstone. Crests and scarps occur on dolerite and sandstone with middleslopes and footslopes predominantly on mudstone and shale. The topography is undulating to flat. More than 70% of the terrain consists of pediments (Scheepers, Smit & Ludick 1984). Consequently the research reported on in this paper was restricted to the pediments.

MATERIALS AND METHODS

Six micro-scale degradation gradients, extending from patches in good range condition to severely degraded patches (Figure 2), were selected on two soil types. The soil types were chosen to include the soil types most common in the region, namely sand-loam soils and duplex soils. The selected soils were classified (FAO classification) as Brunic Luvisol (duplex soil) and Rhodic Ferralsol (sand-loam soil) (Dudal 1968; Macvicar et al. 1977). Four micro-scale degradation gradients were studied on the Brunic Luvisol and two on the Rhodic Ferralsol. All sample plots were located in two grazing units on adjacent farms.

One metre wide belt transects were marked out to delineate the degradation gradients (Figure 2). The transects were subdivided into one square metre micro-plots. The following measurements were conducted in each micro-plot:

(a) Total basal cover was determined with 5x1 m line transects (Canfield 1941; Brown 1954).

(b) The vegetation composition was recorded with a pin and a 100 point grid placed over each micro-plot. At each of the 100 points the pin was lowered and the nearest grass species recorded.

(c) Soil crust hardness was measured with a falling pin penetrometer. The pin was lifted 300mm, dropped and the depth of penetration recorded. This procedure was repeated twenty times per micro-plot, on a random sampling basis.

(d) A soil auger, 30mm in diameter, was used to extract two soil samples (approximately 300g), to a depth of 200mm. The gravimetric soil moisture content of these soil samples was established according to the method described by Hillel (1982).

(e) The depth of the A-horizon was determined with a soil auger.

(f) The degree of vegetation utilisation was subjectively assessed on a scale of 1-6, where:

U1 = no utilisation; U2 = slight utilisation; U3 = moderate utilisation; U4 = moderate severe utilisation; U5 = severe utilisation and U6 = extremely severe utilisation.

The slope, direction of run-off and other relevant micro-topographical aspects were recorded. The on-site precipitation for thirty days prior to the research was recorded. Samples of both soil types were analysed physically and chemically.

The range condition assessment module of the PUK model for grassland dynamics (Bosch _et_ _al_. 1988; Bosch, Kellner & Scheepers 1989) was used to assess the range condition of each micro-plot. A range condition score of above 80% represents excellent range condition whereas a score of below 30% is indicative of severely degraded vegetation.

To ease interpretation of floristic changes, the recorded grass species were classified according to their ecologic status as determined by Janse van Rensburg (1987).

Vegetation cover, crust penetration, depth of A-horizon (erosion extent), range condition and soil moisture content were cross-correlated, using linear regressions, to determine the respective correlation coefficients and coefficients of variation.

RESULTS AND DISCUSSION

Soil analyses

The recorded sodium content, pH and electric conductivity of the A-horizon do not differ significantly for the two soil types (Table 1). Low values of exchangeable sodium percentage were obtained for both soils, with a slightly higher value recorded for the Brunic Luvisol. The results indicate that both soils contain no outstanding characteristics which might have a significantly deleterious effect on their physical and chemical properties.

Vegetation retrogression

The micro-scale vegetation retrogression, caused by patch-overgrazing, closely resembles the compositional changes ascertained by large-scale vegetation retrogression studies conducted in the study area (Figure 3) (Janse van Rensburg 1987; Bosch 1989). There is a persistent trend of reduction in palatable tufted perennial grasses followed by progressive increases in lower ecologic status tufted perennial grasses, low ecologic status creeping grasses and annual and pioneer grasses of low ecologic status. Eventually xeric karroid shrub invasion occurs (Table 2). The recorded vegetation composition changes depict the invasion process of the xeric karoo biome into the more mesic climatic climax grasslands (Bosch 1989).

Range condition of patches is negatively influenced by increased patch-overgrazing (Table 3). The greatest decline in range condition within a single micro-scale degradation gradient, namely from 68,4% to 15,9%, was recorded for degradation gradient 6. The only noteworthy exception, in an otherwise persistent decline in range condition, was recorded for micro-plot 4.6.

The floristic changes were found to be very similar for the two soil types (Table 2). However, xeric karroid shrubs were not recorded on the Rhodic Ferralsol. An explanation may be that vegetation on the Brunic Luvisol has a higher rate of deterioration due to the higher erosion susceptibility of this soil type (Tainton 1984). This inference is substantiated by the absence of an A-horizon in severely degraded patches on the Brunic Luvisol in contrast to the Rhodic Ferrasol (Table 3). Furthermore, the recorded reduction in basal cover with increased degradation is slightly less on the Rhodic Ferralsol compared to the Brunic Luvisol.

The average decline in basal cover, for the six degradation gradients, was 90%. Within one severely degraded patch a basal cover of 0,5% was recorded with 56% of the vegetation consisting of annual pioneer species. An initial sharp decline of basal cover was recorded for all degradation gradients (Table 3). This reduction of basal cover is probably the result of excessive removal of shoot-apexes which induces a rapid decrease of less grazing-tolerant species (Booysen, Tainton & Scott 1963). Consequently large, tufted perennial grasses of high ecologic status are replaced by tufted perennials and creeping grasses of lower ecologic status.

On four degradation gradients a minor increase of basal cover was recorded in micro-plots in mediocre range condition compared to micro-plots in better condition (Table 3). The vegetation of these micro-plots predominantly consists of lower ecologic status tufted perennials and creeping grasses (Table 2). Moderate to moderate-severe utilisation enhances lateral growth of these species, with a consequent increase in basal cover (Milchunas et al. 1989). However, enhanced utilisation levels and subsequent habitat degradation stress the vegetation beyond a tolerance threshold, resulting in another sharp decline of basal cover (Table 3).

The severity of utilisation within degraded patches is illustrated by the lack of high ecologic status species in these patches. Patches in mediocre condition are less severely grazed with minimal utilisation in good range condition patches (Table 3).

Low basal cover together with annual and pioneer vegetation characterise patches in poor condition. The result is a severe reduction in biomass production within overgrazed patches (Snyman, Opperman & Van den Berg 1980; Snyman & Van Rensburg 1986). The sheep are eventually forced to graze on less degraded patches adjacent to severely degraded patches. Consequently these patches are increasingly overstressed, resulting in the expansion of patches in poor condition. This phenomenon has important management implications. If the disproportionate utilisation of available fodder, due to patch-selective grazing, is not taken into account when stocking rates are calculated, it could be expected that the total sward will eventually retrogress to a poor range condition. This is substantiated by the fact that the good range condition patches surveyed already displayed vegetation retrogression trends (Table 3). The range condition score of 69,9%, recorded for the micro-plot in best condition, falls 30% short of the optimum (Figure 3).

Habitat degradation

Substantial habitat degradation occurs concomitant with vegetation retrogression (Table 3). The exposure of the soil surface to the elements results in a compacted soil surface crust. Furthermore, excessive trampling by livestock in overutilised patches enhances soil compaction (Warren et al. 1986; Abdel-Magid, Trlica & Hart 1987). A decrease in soil crust penetration with increasing degradation was recorded for all gradients (Table 3). The average crust penetration recorded for degradation gradient 2, decreased from 41mm to 13mm within a distance of five metres.

Gravimetric soil moisture recordings indicate that the rainfall effectivity is significantly reduced in degraded patches. One hour after an 18mm rainfall event (thunder-shower), an average moisture content of 24,2% was recorded for the micro-plot in degradation gradient 6 in best range condition. In contrast the average soil moisture content of the most degraded micro-plot was 12,5% - a difference of 48% (Table 3). An average decrease in soil moisture content of 55% was obtained for the six micro-scale degradation gradients.

The unexpected rise in soil moisture content recorded for the last two micro-plots of degradation gradient 1 could be ascribed to micro-topography. The most degraded micro-plot bordered on a slight depression within the degraded patch which resulted in the creation of a small catchment area. The higher soil moisture contents of the denuded micro-plots are ascribed to a subsurface redistribution flux of soil moisture from the soil beneath the small catchment area towards adjacent soil. The poor range condition is probably maintained because of the soil crusting, extent of erosion and low basal cover recorded. The slightly lower initial soil moisture recorded for some degradation gradients could be ascribed to higher transpiration rates of climax vegetation with high basal cover and biomass production. Furthermore, a portion of the precipitation is intercepted by the above-ground phytomass which would evaporate after rain.

Increasing topsoil losses were recorded as the vegetation deterioration advances (Table 3). The huge and abrupt differences in A-horizon thickness are however partially the result of sediment deposits on the fringes of degraded patches and within patches in better state of health. Subsequent gains in A-horizon depth, at the expense of degraded patches, explain the differences in A-horizon depth recorded between micro-plots 3.1 and 3.2 as well as between 3.5 and 3.6 (Table 3). The determined sediment loss due to erosion poses a threat to grassland resource conservation.

Intercorrelation of habitat factors

Generally high correlation coefficients were obtained with varying coefficients of variation (Table 4A). All habitat factors monitored were significantly intercorrelated. Consequently habitat factors act in concert as grazing pressure increases and ecosystem degradation sets in.
Other conclusions drawn from mean correlation coefficients and coefficients of variation (Table 4B) are:

(a) Gravimetric soil moisture content is primarily determined by soil crusting - an average correlation coefficient of 0,91 was recorded between these two parameters, with the average coefficient of variation only 13,2%. This is to be expected since crusting reduces soil infiltrability (Stallings 1957, O'Brien 1984).

(b) Basal cover reduction was principally related to increasing loss of topsoil. Seed is carried away, seed germination is restricted and seedling establishment hampered by rampant erosion. Vegetation is pedestilled and eventually eroded away (Stallings 1957, Roux & Opperman 1986).

(c) The extent of erosion was highly correlated with percentage basal cover. Similar results were obtained by Wood, Wood & Tromble (1987). However, the degree of soil crusting influences the loss of topsoil most significantly (Table 4B). This could be ascribed to increasing and accelerated run-off because infiltrability declines when the soil surface is sealed.

(d) Soil crust penetration was principally related to depth of A-horizon and gravimetric soil moisture content. Soil crusting and compaction will be affected by soil wetness. Therefore it can be assumed that the recorded soil crust penetration data is somewhat distorted due to differences in gravimetric soil moisture content. It can, however, be accepted that the large differences in soil crust penetrations between micro-plots in good range condition and denuded micro-plots, are the result of soil surface crusting and soil compaction due to excessive livestock trampling. This inference is substantiated by the continued decrease in soil crust penetration recorded for degradation gradient 1 inspite of soil moisture increases recorded for severely degraded micro-plots (Table 3).

(e) Range condition is highly correlated with basal cover. This could be ascribed to the creation of niches for species of lesser ecologic status as the vegetation cover declines. Lesser ecologic status grasses and pioneer grasses are superiorly adapted to colonise denuded areas.

The low correlation of range condition with gravimetric soil moisture content, crust penetration and depth of A-horizon is the result of a lag in compositional vegetation retrogression whereas habitat degradation accelerates (Table 3). After an initially abrupt decline in range condition the vegetation displays a resilience to regressive processes. The threshold of resilience is only exceeded some time after significant habitat degradation has commenced. Thereafter range condition declines abruptly (Table 3).

ECOSYSTEM MODIFICATION MODEL

The above established vegetation and habitat degradation processes were supplemented with existing knowledge to summarise and discuss relevant ecosystem modification dynamics on the basis of a descriptive ecosystem modification model (Figure 4).

Long-term mismanagement and exploitation of rangeland vegetation diminishes plant cover and changes the species composition (Tables 2 and 3). Vegetation degradation in the western grassland biome is characterised by a reduction of perennial tuft grasses of high ecologic status. Escalating deterioration results in sequential increases in lower ecologic status grass species, pioneer species, annual species and invader species (Janse van Rensburg 1987; Bosch 1989). Eventually the grassland is invaded by xeric karroid shrubs (Figure 3, Table 3).

Snyman & Van Rensburg (1986) determined that climax, subclimax and pioneer grassland vegetation produced an average of 0,57g; 0,23g and 0,07g above-ground phytomass, respectively, for each litre of water evapotranspirated. The deteriorating biomass production, decreasing plant cover and water use efficiency results in a depletion of biologically active organic matter. The soil fertility declines, soil moisture retention decreases and soil surface aggregation is deminished due to the decrease in humic substances (Stallings 1957). The extent of soil surface crusting and soil aggregation is strongly affected by the humic fraction present in the soil (Du Plessis & Schainberg 1985).

The interactive processes of over-utilisation, declining plant cover and reduced biomass production result in an increased exposure of the soil to the elements (Figure 4). Consequently evaporation and wind erosion susceptibility is enhanced and soil temperatures increase (Johnston, Dormaar & Smoliak 1971). Direct raindrop impact on the bared soil surface shatters and breaks down the soil aggregates. The fine soil particles clog the pores between aggregates and form a slick layer of dispersed mud (Farres 1978; Hillel 1982). Eventually an impenetrable, compacted soil surface crust is created (Table 3). As a result of progressive reduction in soil infiltrability, run-off and evaporation are magnified (O'Brien, 1984). Wilcox, Wood & Tromble (1985) conclude that plant cover primarily determines infiltrability of soils. The direct impact of raindrops amplifies splash erosion. Fine soil particles are churned up, suspended in the rain-water and carried away by run-off water (Stallings 1957).

Due to the absence of vegetation, which retains overland flow, and poor infiltration rates, accelerated and increased run-off occurs (Thurow, Blackburn & Taylor 1988). The resultant increase in sediment loss, decline in soil moisture (Table 3) and eventual lowering of the water-table negatively influences the stability of the ecosystem.

The detrimental consequences of erosion to the rangeland environment , referred to by Stallings (1957) and Roux & Opperman (1986), are summarised in Figure 4.

Habitat degradation inhibits plant reproduction (Figure 4). Vegetation seldom reaches the reproductive stage, especially in semi-arid regions, when severely utilised. Hence seed production is significantly restricted. In particular palatable and higher ecological status species are adversely affected. Seed production, seed germination and seedling survival are hampered by the unfavourable environmental conditions engendered. Consequently the survival of plant populations is endangered.

The end result of these ecosystem degradation processes is a substantial decrease in rainfall effectivity (Figure 4). The ecosystem is modified due to the creation of a more xeric environment (Table 3). The resultant unstable ecosystem displays incessant and extensive changes in response to changes in climate, utilisation and other environmental stresses (Noy-Meir & Walker 1984). The long term consequences of ecosystem degradation are adequately illustrated by, amongst others, desert expansion, xeric shrub invasion and extensive erosion.

CONCLUSIONS

The determined process of patch vegetation change, resulting from patch-overgrazing by sheep, closely resembles macro-scale vegetation retrogression. When utilisation of the vegetation increases beyond an initial threshold of grazing stress resilience, an abrupt decline in basal cover and range condition is recorded. Vegetation retrogression occurs at this stage due to the intolerance of high ecologic status grass species to repeated and excessive shoot-apex removal. Grass species of lesser ecologic status are better adapted to resist grazing pressure and to compete for newly created niches. Consequently these species invade the denuded areas between large, tufted perennials. After the initial sharp decline in range condition, the vegetation displays an inherent resilience to change. While habitat degradation accelerates, range condition decrease lags behind. Continued over-utilisation and habitat degradation stresses the vegetation to such an extent that a second threshold of resilience is exceeded. Thereafter range condition again declines abruptly. Only hardened pioneer species and xeric shrubs are able to colonise the severely degraded patches.

Soil moisture content declines and soil physical conditions deteriorate as vegetation retrogression proceeds. The recorded habitat degradation occurring concomitant with vegetation retrogression reduces rainfall effectivity. The overall ecosystem modification can be described as a desertification process due to the creation of a drier micro-climate. Pseudo-droughts or man-made droughts are created where severe overgrazing occurs. Xeric vegetation is superbly adapted to thrive in these adverse micro-climatic conditions. Consequently the more xeric karoo biome expands at the expense of the climatic climax grassland biome.

The patch-overgrazing and resultant ecosystem modification have a detrimental effect on the stability of semi-arid climatic climax grasslands. The resilience of rangelands to unfavourable climatic conditions and other environmental stress factors is adversely affected by the decrease in rainfall effectivity where patch-overgrazing occurs. Management strategies will have to be devised and/or adjusted to minimise patch-overgrazing. The disproportionate utilisation of available fodder should be taken into account when stocking rates are calculated.

Results indicate that the ecosystem modification would adversely affect prospects of effective rest-restoration of degraded areas. To reverse the retrogression processes, extensive mechanical and managerial inputs may be required, depending on the degree of habitat degradation. Field experiments are required to establish at which point of habitat degradation rest-restoration will be impossible through normal management procedures.

The semi-arid climatic climax grasslands of southern Africa, under current levels of patch-grazing, can be regarded as a resource under siege.

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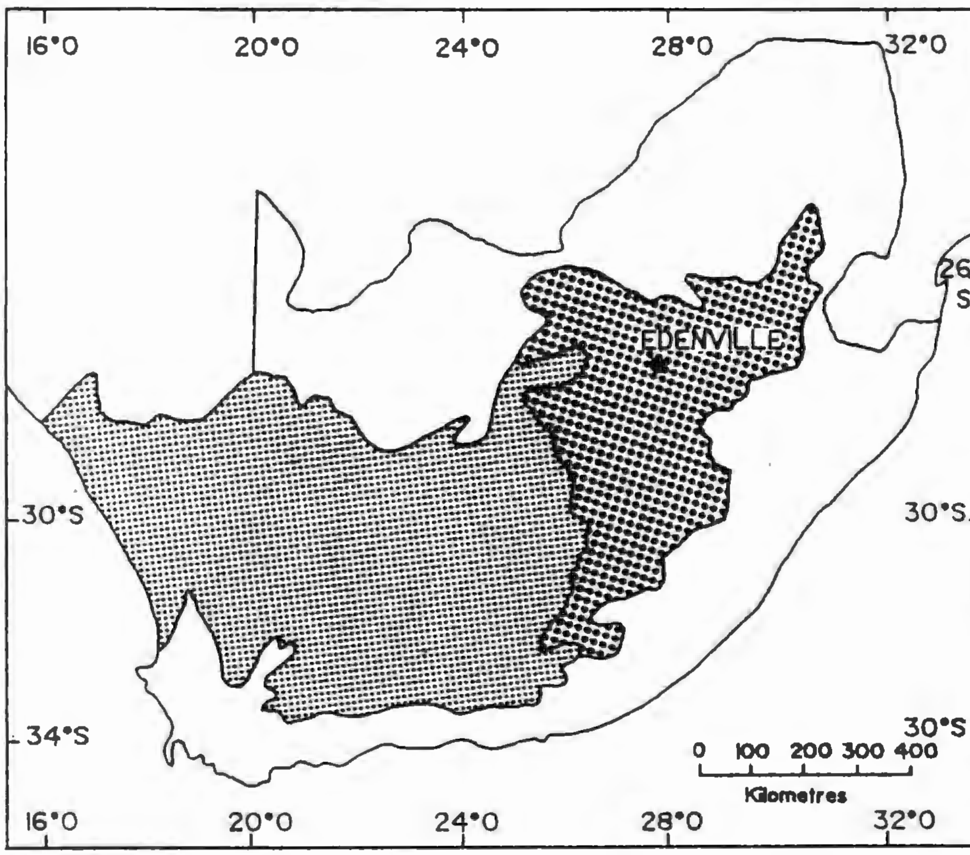
CAPTIONS FOR FIGURES

Figure 1. The semi-arid climatic climax grasslands and arid Karoo biome of southern Africa.

Figure 2. A typical patch-mosaic encountered in the study area. One metre wide belt transects, extending from patches in good range condition to degraded patches, delineate the selected degradation gradients.

Figure 3. The compositional changes ascertained by extensive grassland degradation studies conducted in the study area. The diagram represents patterns of long-term vegetation retrogression for climatic climax grassland on pediments in the 600-650mm p.a. rainfall zone (adapted from the range condition assessment module of the PUK model, Bosch *et al.* 1988; Bosch, Kellner & Scheepers 1989).

Figure 4. A descriptive ecosystem modification model illustrating the biotic and abiotic interactions and degradation dynamics associated with rangeland retrogression due to over-utilization.



LEGEND

Semi-arid grasslands

Arid Karoo biome

● Study area

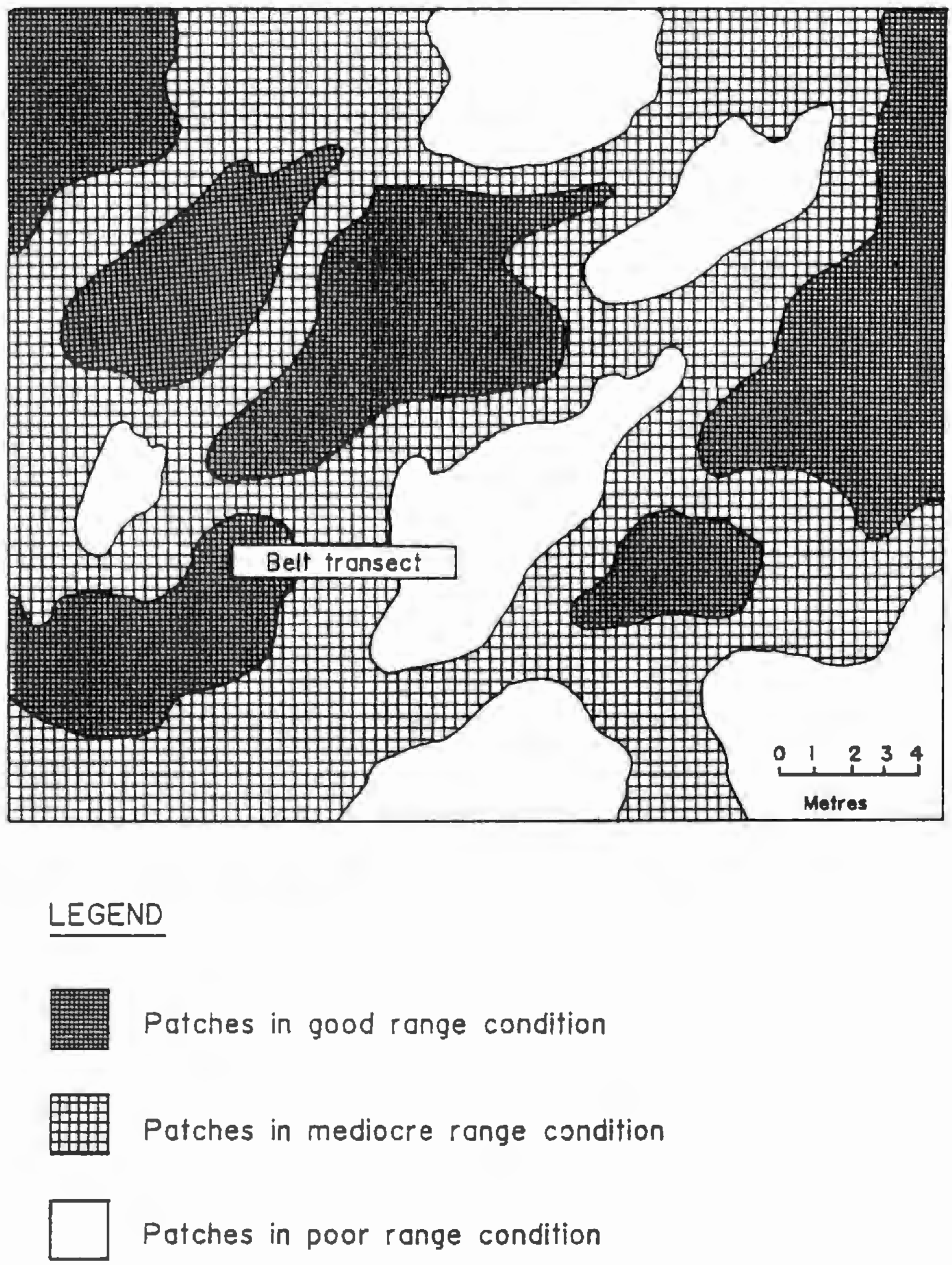
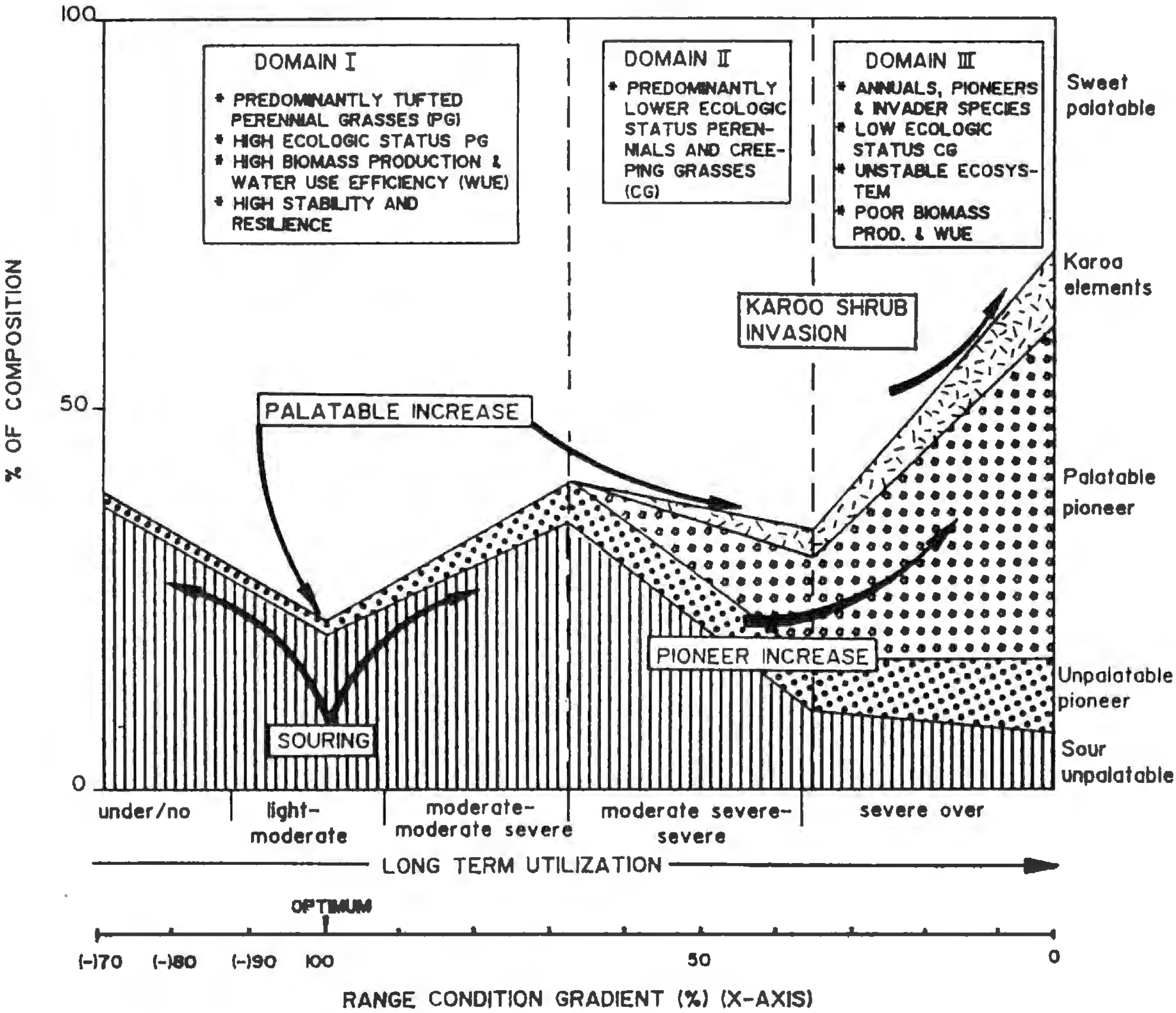

Belt transect
0 1 2 3 4
Metres
LEGEND
Patches in good range condition
Patches in mediocre range condition
Patches in poor range condition

Table 1. Soil analyses

Soil properties	Rhodic Ferralsol		Brunic Luvisol	
Horizon	A2	B2	A2	B2
soil sample depth (mm)	0-230	250-550	0-150	180-500
Sand (%)	73.6	63,6	65,6	45,6
Silt (%)	9,4	6,4	13,4	10,4
Clay (%)	17.0	30.0	21,0	44,0
Na (me/100g)	0,0	0,1	0,1	0,6
pH (H_2O)	7,1	7,1	6,2	6,3
pH (KCl)	5,3	5,1	5,3	5,2
[1]EC (ds/m)	0.2	0,2	0,2	0,5
Base saturation (%)	81.7	87,9	108,0	109,9
[2]ESP (%)	0.0	1,1	2,3	7,2

[1]EC = Electric conductivity

[2]ESP = Exchangeable sodium percentage



100
50
0
% OF COMPOSITION
DOMAIN I
* PREDOMINANTLY TUFTED PERENNIAL GRASSES (PG)
* HIGH ECOLOGIC STATUS PG
* HIGH BIOMASS PRODUCTION & WATER USE EFFICIENCY (WUE)
* HIGH STABILITY AND RESILIENCE
DOMAIN II
* PREDOMINANTLY LOWER ECOLOGIC STATUS PERENNIALS AND CREEPING GRASSES (CG)
DOMAIN III
* ANNUALS, PIONEERS & INVADER SPECIES
* LOW ECOLOGIC STATUS CG
* UNSTABLE ECOSYSTEM
* POOR BIOMASS PROD. & WUE
KAROO SHRUB INVASION
PALATABLE INCREASE
PIONEER INCREASE
SOURING
Sweet palatable
Karoo elements
Palatable pioneer
Unpalatable pioneer
Sour unpalatable
under/no
light-moderate
moderate-moderate severe
moderate severe-severe
severe over
LONG TERM UTILIZATION
OPTIMUM
(-)70
(-)80
(-)90
100
50
0
RANGE CONDITION GRADIENT (%) (X-AXIS)

TABLE 2. Compositional changes recorded on micro-scale ecosystem degradation gradients

Degradation gradient & Soil type	Micro-plot no.	Species composition (%)					
		Unpalatable tufted perennials *(Cymbopogon plurinodis Elionurus muticus)*	Palatable tufted perennials *(Themeda triandra)*	Lower ecologic status tufted perennials *(Panicum stapfianum, Eragrostis curvula & Setaria sphacelata)*	Low ecologic status creeping grasses *(Eragrostis lehmanniana, Digitaria argyrograpta & Cynodon dactylon)*	Annuals & pioneers *(Aristida congesta, Microchloa caffra Sporobolus discosporus & Trichoneura grandiglumis)*	Invader species (xeric Karoo shrubs)
1 Brunic Luvisol	1.1	5	36	18	25	16	-
	1.2	5	27	23	34	12	-
	1.3	-	9	43	29	19	-
	1.4	-	10	52	25	13	-
	1.5	2	11	42	25	20	-
	1.6	-	5	9	53	31	2
	1.7	-	-	4	44	48	4
2 Brunic Luvisol	2.1	-	42	46	-	12	-
	2.2	-	13	52	7	28	-
	2.3	-	8	24	31	33	5
	2.4	-	10	2	33	45	10
	2.5	-	7	4	29	51	9
3 Brunic Luvisol	3.1	7	54	37	-	2	-
	3.2	-	22	47	15	15	1
	3.3	-	2	28	39	27	4
	3.4	-	3	10	57	28	2
	3.5	-	8	-	65	27	-
	3.6	-	-	-	63	30	7
4 Rhodic Ferrasol	4.1	-	64	19	15	2	-
	4.2	-	35	18	23	23	-
	4.3	-	17	21	15	47	-
	4.4	-	4	18	9	69	-
	4.5	-	5	22	9	64	-
	4.6	-	2	28	51	19	-
	4.7	-	-	31	13	56	-
5 Rhodic Fer= ralsol	5.1	-	68	20	12	-	-
	5.2	2	25.	23	37	13	-
	5.3	-	9	26	27	38	-
	5.4	-	10	31	32	27	-
	5.5	-	12	40	30	18	-
	5.6	-	7	16	28	39	-
	5.7	-	3	17	23	57	-
6 Brunic Luvisol	6.1	4	64	15	9	8	-
	6.2	3	28	19	26	18	6
	6.3	3	-	-	69	15	13
	6.4	-	1	2	66	11	20
	6.5	-	2	-	23	48	27

TABLE 3. The recorded biotic and abiotic changes resulting from micro-scale ecosystem retrogression due to patch overgrazing

Degradation gradient/ Length/ Soil type	Micro= plot no.	Basal cover (%)	Range con= dition (%)	Crusting (average depth of pin pene= tration (mm))	Average gravimetric soil moisture content (%)	Depth of A-horizon (mm)	Utili= zation
1 [1]	1.1	7.6	49.3	52	18.3	130	u_2
7 m	1.2	6.6	43.8	30	11.3	130	u_4
Brunic	1.3	6.9	41.3	33	11.6	130	u_3
Luvisol	1.4	6.1	42.9	22	8.9	80	u_4
	1.5	3.4	41.5	20	7.9	40	u_5
	1.6	1.6	27.4	15	9.7	10	u_6
	1.7	0.9	16.8	15	10.2	0	u_6
2 [1]	2.1	7.7	51.5	41	16.2	140	u_2
5 m	2.2	8.2	36.8	44	16.6	140	u_3
Brunic	2.3	4.7	31.8	40	15.9	110	u_4
Luvisol	2.4	1.3	23.7	26	8.1	60	u_5
	2.5	0.8	18.0	13	7.7	0	u_6
3 [1]	3.1	11.2	63.1	45	11.5	150	u_1
6 m	3.2	6.8	38.9	47	14.6	210	u_3
Brunic	3.3	3.6	33.1	44	14.3	180	u_4
Luvisol	3.4	2.7	27.2	39	9.1	150	u_5
	3.5	1.7	24.1	30	6.5	70	u_6
	3.6	0.6	18.8	16	4.6	0	u_6
6 [2]	6.1	9.8	68.4	62	24.2	150	u_1
5 m	6.2	6.9	47.8	62	23.0	130	u_3
Brunic	6.3	5.3	31.0	51	17.1	70	u_4
Luvisol	6.4	2.7	29.8	36	14.2	20	u_5
	6.5	0.5	15.9	35	12.5	0	u_6
4 [3]	4.1	8.9	66.6	28	9.9	200	u_1
7 m	4.2	6.3	41.9	24	10.8	200	u_3
Rhodic	4.3	7.1	29.1	25	10.5	180	u_4
Ferralsol	4.4	6.9	22.4	25	12.8	140	u_4
	4.5	4.8	18.6	25	8.2	110	u_5
	4.6	2.4	27.4	18	6.6	60	u_6
	4.7	1.5	18.7	15	6.1	30	u_6
5 [3]	5.1	10.2	69.9	34	15.7	210	u_1
7 m	5.2	7.9	43.8	30	14.6	210	u_3
Rhodic	5.3	7.1	32.2	23	12.9	180	u_4
Ferralsol	5.4	7.6	36.2	23	12.5	140	u_5
	5.5	3.7	32.3	18	7.2	80	u_5
	5.6	2.1	24.1	15	6.1	30	u_6
	5.7	1.0	19.9	16	6.1	20	u_6

[1] Last rainfall event: two nights before - 9 mm - duration: 45 minutes. Total rainfall for previous 30 days: 61 mm

[2] Last rainfall event: 60 minutes before - 18 mm - duration: 40 minutes. Total rainfall for previous 30 days: 85mm

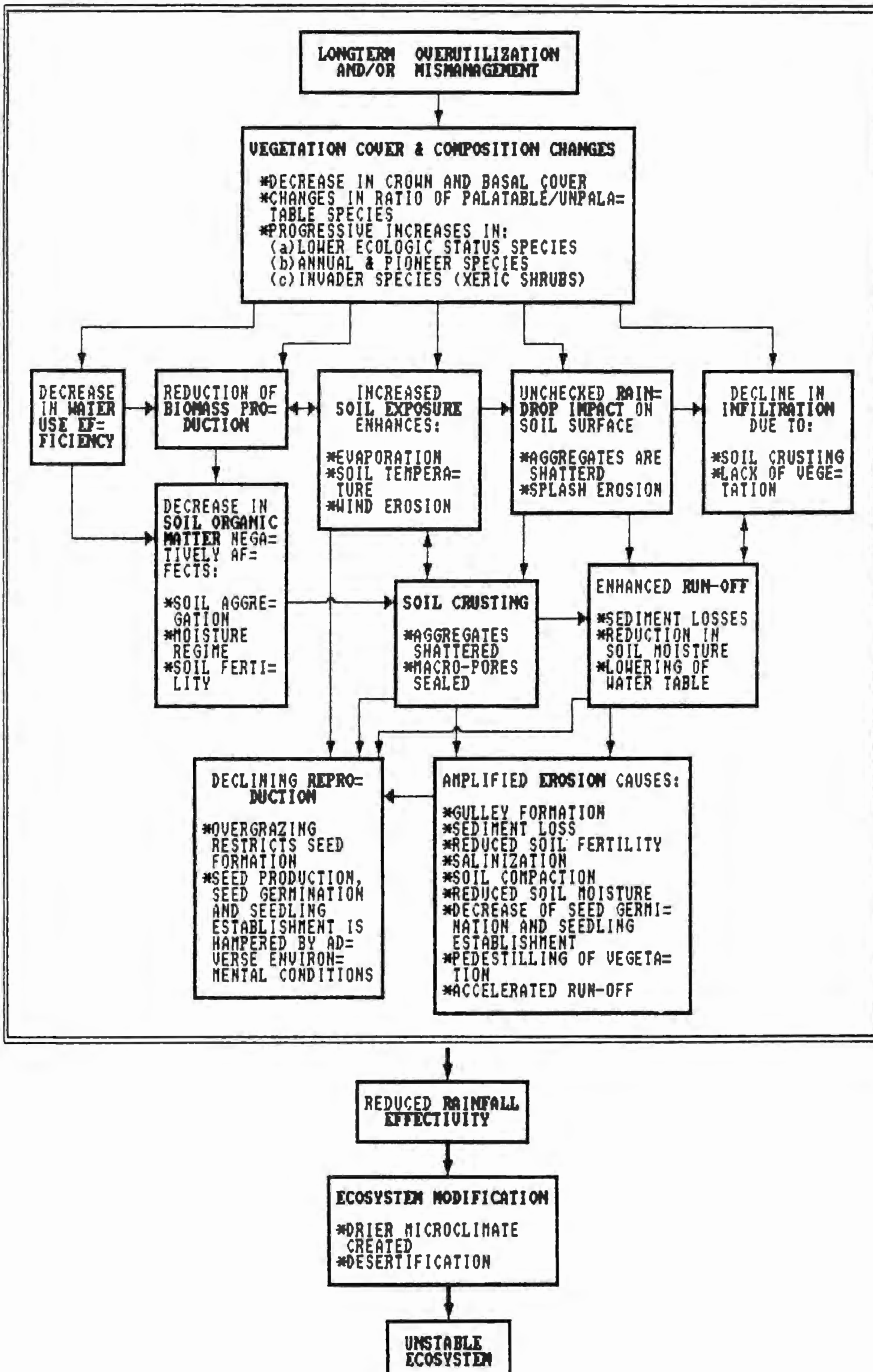
[3] Last rainfall event: the night before - 6 mm - duration: 80 minutes. Total rainfall for previous 30 days: 76mm

TABLE 4A. Correlation coefficients and coefficients of variation (in brackets) obtained from cross-correlations of ecosystem degradation data

	Basal cover						Gravimetric soil moisture content						Crust penetration						Depth of A-horizon					
Degradation gradient number	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Gravimetric soil moisture content	0.55 (52.8)	0.94 (30.2)	0.61 (78.3)	0.96 (23.0)	0.83 (30.4)	0.98 (13.8)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crust penetration	0.77 (35.9)	0.91 (36.9)	0.74 (66.7)	0.94 (28.4)	0.95 (17.2)	0.93 (23.8)	0.91 (14.1)	0.94 (13.5)	0.91 (18.3)	1.00 (1.3)	0.76 (18.5)	0.95 (13.4)	-	-	-	-	-	-	-	-	-	-	-	-
Depth of A-horizon	0.97 (14.1)	0.95 (28.7)	0.63 (76.7)	0.96 (21.8)	0.92 (21.2)	0.96 (19.3)	0.58 (27.3)	0.95 (12.5)	0.95 (14.2)	0.97 (7.5)	0.75 (19.0)	0.98 (7.9)	0.83 (30.3)	0.99 (6.2)	0.97 (8.5)	0.98 (6.2)	0.86 (11.2)	0.94 (11.5)	-	-	-	-	-	-
Range condition	0.90 (14.3)	0.90 (19.1)	0.99 (6.5)	0.97 (13.7)	0.67 (38.3)	0.89 (19.0)	0.41 (30.2)	0.84 (23.8)	0.61 (37.9)	0.96 (15.7)	0.30 (49.2)	0.85 (22.4)	0.73 (22.5)	0.83 (24.5)	0.75 (31.9)	0.89 (25.8)	0.55 (43.3)	0.95 (13.9)	0.84 (18.0)	0.89 (19.6)	0.59 (38.8)	0.95 (16.9)	0.71 (36.1)	0.81 (24.8)

TABLE 4B. Mean correlation coefficients and coefficients of variation (in brackets) for inter-cor= related ecosystem degradation data

	Basal cover	Gravimetric soil moisture content	Crust penetration	Depth of A-horizon
Gravimetric soil moisture content	0,81 (38,0)	-	-	-
Crust penetration	0,87 (34,8)	0,91 (13,2)	-	-
Depth of A-horizon	0,90 (30,3)	0,86 (14,7)	0.93 (12,3)	-
Range condition	0,88 (18,5)	0,66 (29,9)	0.78 (27,0)	0,80 (25,7)


LONGTERM OVERUTILIZATION AND/OR MISMANAGEMENT
VEGETATION COVER & COMPOSITION CHANGES
*DECREASE IN CROWN AND BASAL COVER
*CHANGES IN RATIO OF PALATABLE/UNPALA= TABLE SPECIES
*PROGRESSIVE INCREASES IN:
(a)LOWER ECOLOGIC STATUS SPECIES
(b)ANNUAL & PIONEER SPECIES
(c)INVADER SPECIES (XERIC SHRUBS)
DECREASE IN WATER USE EF= FICIENCY
REDUCTION OF BIOMASS PRO= DUCTION
INCREASED SOIL EXPOSURE ENHANCES:
*EVAPORATION
*SOIL TEMPERA= TURE
*WIND EROSION
UNCHECKED RAIN= DROP IMPACT ON SOIL SURFACE
*AGGREGATES ARE SHATTERD
*SPLASH EROSION
DECLINE IN INFILTRATION DUE TO:
*SOIL CRUSTING
*LACK OF VEGE= TATION
DECREASE IN SOIL ORGANIC MATTER NEGA= TIVELY AF= FECTS:
*SOIL AGGRE= GATION
*MOISTURE REGIME
*SOIL FERTI= LITY
SOIL CRUSTING
*AGGREGATES SHATTERED
*MACRO-PORES SEALED
ENHANCED RUN-OFF
*SEDIMENT LOSSES
*REDUCTION IN SOIL MOISTURE
*LOWERING OF WATER TABLE
DECLINING REPRO= DUCTION
*OVERGRAZING RESTRICTS SEED FORMATION
*SEED PRODUCTION, SEED GERMINATION AND SEEDLING ESTABLISHMENT IS HAMPERED BY AD= VERSE ENVIRON= MENTAL CONDITIONS
AMPLIFIED EROSION CAUSES:
*GULLEY FORMATION
*SEDIMENT LOSS
*REDUCED SOIL FERTILITY
*SALINIZATION
*SOIL COMPACTION
*REDUCED SOIL MOISTURE
*DECREASE OF SEED GERMI= NATION AND SEEDLING ESTABLISHMENT
*PEDESTILLING OF VEGETA= TION
*ACCELERATED RUN-OFF
REDUCED RAINFALL EFFECTIVITY
ECOSYSTEM MODIFICATION
*DRIER MICROCLIMATE CREATED
*DESERTIFICATION
UNSTABLE ECOSYSTEM

CHAPTER 5

THE INFLUENCE OF BELOW-AVERAGE RAINFALL ON THE VEGETATIONAL TRAITS OF A PATCH-GRAZED SEMI-ARID GRASSLAND

Manuscript accepted for publication in "The Journal of Arid Environments"

THE INFLUENCE OF BELOW-AVERAGE RAINFALL ON THE VEGETATIONAL TRAITS OF A PATCH-GRAZED SEMI-ARID GRASSLAND

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Abstract

The effect of below-average rainfall on the species basal cover of semi-arid grassland varies between patches representing different stages of degradation. Total basal cover of patches in good condition increased, in contrast to patches in poor condition, due to increases in basal cover of high ecologic status species.

Patches in poor condition expanded at the expense of less degraded patches.

Long-term patch-overgrazing stresses the vegetation beyond a threshold of drought resilience. Consequently the absence of livestock grazing did not prevent retrogression of patches in poor condition in times of drought.

The following hypothesis was formulated: Semi-arid vegetation which has retrogressed beyond a threshold of drought resilience can not rest-recover. Recovery trends in above-average rainfall seasons will be reversed in subsequent below-average rainfall seasons due to the instability of the retrogressed vegetation and lack of resilience to even minor droughts.

Introduction

The semi-arid climatic climax grasslands of southern Africa are characterised by seasonal dry periods which prevail during certain seasons of the year (Booysen & Rowswell, 1983). Rainfall is erratic and occurs mainly in the form of heavy thunder-showers which are of short duration. Below-average rainfall seasons are a common phenomenon (Anonymous, 1984). As yet no studies have been conducted to establish the influence of below-average rainfall seasons on the species basal cover and the patch dynamics of semi-arid grasslands in southern Africa.

Long-term patch-overgrazing by sheep in semi-arid grasslands creates a micro-pattern in which heavily grazed patches alternate with a range of lesser grazed or ungrazed patches (Bakker *et al.*, 1983). The patch-mosaic contains severely degraded patches as well as excellent range condition patches (Fuls & Bosch, 1990). A study was launched in 1988 to monitor the long-term vegetational traits of patches representing varying degrees of long-term over-utilisation, in livestock grazing exclosures, in the 600-650 mm rainfall belt of the climatic climax grasslands of southern Africa. The aim of the ongoing research is to study patch-dynamics as well as the impact of patch-overgrazing, and overgrazing in general, on the resilience of semi-arid grassland vegetation. It is argued that the long-term rest-recovery trends of patches representing varying degrees of over-utilisation/degradation will disclose possible boundaries of rangeland resilience to long-term over-utilisation.

In the first year of the study (7 March 1989 - 6 March 1990) the research plots located in the northern part of the study area received 105 mm less rainfall than the determined long-term regional average of 624 mm p.a.. The rainfall recorded was erratic with long dry spells between rainfall events. On only six occasions was the rainfall recorded for 24 hours in access of 15 mm. This paper reports on the effect thereof on the vegetation and patch dynamics of patches representing varying degrees of degradation or range condition.

Methods

The study was conducted in the Koppies district in the 600-650 mm p.a. rainfall belt of the climatic climax grasslands of southern Africa. The topography is undulating to flat with more than 70% of the area consisting of pediments (Scheepers *et al*., 1984). The research reported on here was restricted to pediments. The study was conducted on Luvic phaeozem soils (Dudal, 1968; Macvicar *et al*., 1977).

Three 30x30 m research plots were selected to include a range of patches representing varying stages of retrogression. The plots were fenced-off in February 1989 to exclude livestock grazing. In each macro-plot eight 2x1 m permanent micro-plots were established. The micro-plots were established within patches in varying condition and on boundaries between these patches.

A line intercept method was used to record species basal cover in the micro-plots (Canfield, 1941; Brown, 1954). A metal frame containing 5 x 2m steel wire line transects was used for vegetation surveys. The anchor holes of the metal frame correspond with pegs delineating the 2xlm micro-plots. The anchor holes and pegs in the soil ensure exact spatial resampling of the 5 x 2m line transects in subsequent vegetation surveys.

The first sampling of the permanent micro-plots was done in March 1989 (late summer). The seasonal variation of grassland cover (Morris & Müller, 1970) implies that subsequent resampling of micro-plots must be done at comparable stages of the growing season. Resampling of the micro-plots was therefore conducted in March 1990. The 1989 and 1990 data were compared to assess vegetational traits, for a below-average rainfall season, after 12 months of livestock grazing exclosure. The recorded grass species were classified according to their ecologic status (Janse van Rensburg, 1987; Bosch, 1989) to ease interpretation of vegetational trends.

Results and Discussion

Patches in good condition

A significant increase in total basal cover, ranging from 13,5% to 65,3%, was recorded for all micro-plots located in the middle of patches in good condition (Table 1A, 1B & 1C). The increases of total basal cover are attributable to increases of basal cover of large tufted perennial grass species of high ecologic status. In contrast the basal cover of lower ecologic status grasses did not change or declined slightly. The basal cover increases of large tufted perennial species, in spite of adverse climatic conditions, are ascribed to the high rainfall effectivity in patches in good condition (Fuls & Bosch, 1990). Rain-water run-off from degraded patches onto the non-degraded patches probably contributed to more favourable moisture regimes within patches in good condition.

Results indicate that high ecologic status vegetation is able to withstand periodic droughts without losses in basal cover, if not utilised. Consequently patches in good condition can be regarded as stable.

Patches in mediocre condition

Both micro-plot 2.4 and 2.8 were located on transition zones in mediocre condition between patches in good and poor condition. These micro-plots did not display significant changes in total basal cover (Table 1B). Basal cover of high ecologic status grasses increased whereas basal cover of annual grasses and pioneer creeping grasses decreased. The amount of precipitation and the effectivity of the rainfall were probably sufficient to sustain growth of perennial tuft grasses but insufficient for sustained growth and establishment of annuals and pioneer grass species.

Patches in poor condition

Substantial decreases in total basal cover were recorded for micro-plots located in the middle of patches in poor condition (Table 1A, 1B & 1C). Decreases in access of 35% were not uncommon. A decrease of total basal cover of 94,2% was recorded for micro-plot 3.2 (Table 1C). In contrast micro-plot 3.8, located in a patch in good condition a few metres away, showed an increase of total basal cover of 65,3%.

The increase of basal cover recorded for micro-plot 1.8, located in a degraded patch, is ascribed to micro-topography. This micro-plot was situated in a slight depression, resulting in a small catchment area for run-off water. Consequently the vegetation was subjected to more favourable moisture regimes.

The differences in vegetational traits, between patches in good and poor condition, can be explained by differences in rainfall effectivity. Fuls & Bosch (1990) conclude that patches in poor condition are subjected to enhanced droughts due to habitat degradation. A drier micro-climate is created in extensively overgrazed patches. The low, erratic rainfall in combination with reduced rainfall effectivity results in the death of vegetation in degraded patches. Therefore the vegetation of degraded patches can be regarded as unstable in times of drought. Rapid retrogression occurs in response to increases in environmental stress.

Patch-boundaries

All micro-plots located inside patches in good or mediocre condition but bordering on patches in lesser condition, showed a decrease in total basal cover (Table 1A, 1B & 1C). Substantial decreases of basal cover of high ecologic perennial grasses were recorded for micro-plots 2.1 and 2.2 (Table 1B). These results imply that poor moisture regimes engendered in degraded patches, due to ecosystem modifications, adversely effect adjoining vegetation of patches in better condition. This leads to an expansion of the degraded patches at the expense of less degraded patches in times of drought, in spite of livestock grazing exclusion.

Micro-plots located inside patches in poor condition but bordering on patches in better condition, generally showed a decline in total basal cover. This indicates that the vegetation of patches in poor condition does not benefit from the better moisture regimes of adjacent patches in good condition. The only exception was recorded for micro-plot 3.7. No micro-topographical or other reasonable explanation can be given for the increase in total basal cover recorded for this sample plot.

Species and total basal cover changes

An increase of 31,8% (Table 2) in total basal cover intercept was recorded for *Themeda triandra*. This is a large tufted perennial grass species of high ecologic status (Janse van Ransburg, 1987; Bosch, 1989) which was mainly encountered in patches in good condition with high rainfall effectivity. This fact concomitant with livestock grazing exclusion explains the significant increase obtained for the species. All lower ecologic status grass species showed a decrease in total basal cover intercepts. This can be related to the enhanced xeric conditions created in degraded patches as retrogression progresses (Fuls & Bosch, 1990). The decrease in annual and pioneer species is also described to unfavourable climatic conditions for seed germination and seedling establishment in times of drought.

The total basal intercept, for all micro-plots sampled, was 1158,5 cm in 1989. A decline of 6,6%, to 1081,5 cm, was recorded in 1990. This indicates that overall basal cover of rested semi-arid grassland vegetation does not decrease significantly in spite of the below-average rainfall recorded. These results were, however, obtained in rangeland where more than 60% of the rangeland consists of patches in mediocre and good state of health. More degraded rangeland would probably retrogress more significantly in times of drought.

Conclusions

Twelve months of livestock grazing exclusion resulted in significant increases in basal cover of high ecologic status grass species in patches in good condition. The increase of basal cover, in spite of low and erratic rainfall, is ascribed to high rainfall effectivity in patches in good condition and to the stability and resilience of high ecologic status vegetation.

Resting of rangeland in good condition during seasonal dry periods prevents deterioration of the range. However, resting in a year of below-average rainfall does not prevent further degradation of overgrazed, degraded rangeland. It is the authors contention that the system has retrogressed beyond a threshold of drought resilience. When this threshold is surpassed, rapid retrogression occurs in times of drought.

Patches in poor condition expand at the expense of less degraded patches in years of below-average rainfall. This is the result of a spill-over of the adverse micro-climatic conditions of degraded patches into adjoining patches in better condition.

The above mentioned vegetational traits were recorded in a season where the rainfall, although erratic, was only 17% less than the established long-term average annual rainfall. The vegetation was not utilised for 12 months prior to resampling in 1990. A significant increase in any one, or both, of these stress factors would probably cause serious retrogression of patch-grazed semi-arid grasslands. The resilience of rangelands to unfavourable climatic conditions is adversely affected where patch-overgrazing occurs.

The continued retrogression of vegetation of degraded patches deferred from grazing, in contrast to vegetation of patches in good condition, prompts the formulation of the following hypothesis: Semi-arid vegetation which has retrogressed beyond a threshold of drought resilience can not rest-recover. Once vegetation retrogression exceeds this threshold, the system becomes unstable with a lack of resilience to even minor droughts. Consequently any recovery trends due to above-normal rainfall will be reversed in subsequent periods of drought. This implies that semi-arid rangelands, which have retrogressed beyond a threshold of drought resilience, will only be restored by mechanical inputs.

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Table 1. *Measured basal intercept of species (in centimetres) and total basal intercept for 1989 and 1990 samplings of permanent micro-plots lo= cated in or between patches in varying conditions*
Table 1A: *Macro-plot 1*

Micro-plot no.	1.1		1.3		1.4		1.2		1.8		1.5		1.6		1.7	
Patch condition	Good		Good		Good		Mediocre		Poor		Poor		Poor		Poor	
Position of micro-plot	Middle of patch		Middle of patch		Middle of patch		Surrounded by vege= tation in better con= dition		In slight depression in middle of patch		Boundary between mediocre and poor patch		Middle of patch		Boundary between mediocre and poor patch	
Year sampled	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Species																
Tufted perennials of high ecologic status																
Themeda triandra	19.5	30.0	21.5	39.0	32.0	53.5	7.0	13.0			2.0	2.0			4.5	0.5
Digitaria eriantha	2.0	2.0	1.0	4.5	4.0	3.0	0.5	1.0	2.5	2.0	1.0	4.5			5.0	1.0
Tufted perennials of intermediate ecologic status																
Eragrostis curvula	2.5	4.0	1.5	1.0					8.0	8.5						
Aristida bipartita							3.5	4.0								
Tufted perennials of low ecologic status																
Eragrostis obtusa	0.5	-	3.5	2.0	1.0	1.0	3.5	-					0.5	0.5	0.5	1.0
Michrochloa caffra					-	1.5					0.5	-			2.0	2.0
Eragrostis biflora			2.0	-	1.0	1.0										
Creeping grasses of low ecologic status																
Panicum coloratum	23.0	20.5	8.5	10.5	10.5	8.5	10.5	13.0	7.5	10.0	28.0	27.5	18.5	13.0	22.0	15.5
Eragrostis lehmanniana							2.0	3.5								
Cynodon dactylon									-	0.5			6.0	4.0		
Annual species of low ecologic status																
Brachiaria eruciformis	0.5	-	1.5	-	2.0	-	2.0	2.5	2.5	1.0	1.5	-			-	0.5
Aristida congesta			10.0	9.0	6.5	6.0	3.5	5.0	1.5	6.5	11.5	5.0	3.0	3.0	6.5	3.0
Chloris virgata							0.5	-	4.5	4.5	2.5	-	2.0	1.0		
Tragus racemosus							8.0	2.0								
Urochloa panicoides							-	1.0								
Total basal intercept for 10 m line transect	48.0	56.6	50.0	66.0	57.0	74.5	35.0	45.5	35.5	36.0	46.0	39.0	30.0	22.0	40.5	23.0
Change in total basal intercept	Increase of 17.7%		Increase of 32.0%		Increase of 30.7%		Increase of 30.0%		Increase of 1.4%		Decrease of 15.2%		Decrease of 26.7%		Decrease of 43.2%	

Table 1B: *Macro-plot 2*

Micro-plot no.	2.5		2.6		2.7		2.1		2.2		2.4		2.8		2.3	
Patch state of health	Good		Good		Good		Good		Good		Mediocre		Mediocre		Poor	
Position of micro-plot	Middle of patch		Middle of patch		Middle of patch		Boundary between good and poor patch		Boundary between good and poor patch		Transition between good and poor patch		Transition between good and poor patch		Middle of patch	
Year sampled	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Species																
Tufted perennials of high ecologic status																
Themeda triandra	47,5	65,5	19,5	40,0	31,5	50,5	51,5	33,0	19,5	25,5	10,0	14,5	2,0	-		
Tufted perennials of intermediate ecologic status																
Eragrostis curvula	1,0	2,0	-	2,0	3,0	4,5	1,0	0,5	3,0	-						
Tufted perennials of low ecologic status																
Eragrostis obtusa	6,0	3,0					1,0	-	0,5	-			-	0,5		
Eragrostis biflora	1,0	1,0									2,0	-				
Eragrostis plana			2,0	2,5												
Creeping grasses of low ecologic status																
Panicum coloratum	3,5	8,0	15,0	10,5	8,0	5,0	7,0	5,0	15,5	9,5	18,0	20,5	23,5	18,0	7,5	2,5
Cynodon dactylon	2,0	0,5	1,5	-	2,0	1,5	1,0	-			6,0	1,0			5.0	-
Annual species of low ecologic status																
Brachiaria eruciformis					0,5	-										
Aristida congesta	2.0	0,5	6,0	5,5	12,5	3,5			1,0	-	1,5	0,5				
Tragus racemosus											3,0	0,5				
Urochloa panicoides											3,0	-	1,0	-		
Total basal intercept for 10 m line transect	63,0	80,5	44,0	60,5	57,5	65,5	61,5	38,5	64.5	42,5	43,0	48,0	34,5	33,0	14,5	2,5
Change in total basal intercept	Increase of 27,8%		Increase of 37,5%		Increase of 13,9%		Decrease of 37,4%		Decrease of 34,1%		Increase of 9,4%		Decrease of 4,3%		Decrease of 82.7%	

Table 1C: *Macro-plot 3*

Micro-plot no.	3.8		3.6		3.5		3.4		3.7		3.1		3.2		3.3	
Patch condition	Good		Good		Good		Mediocre		Poor		Poor		Poor		Poor	
Position of micro-plot	Middle of patch		Middle of patch		Boundary between good and mediocre patch		Boundary between mediocre and poor patch		Moundary between good and poor patch		Middle of patch		Middle of patch		Middle of patch	
Year sampled	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Species																
Tufted perennials of high ecologic status																
Themeda triandra	8,5	20,5	15,5	31,5	28,5	27,5	11,5	9,5			2,0	1,0				
Tufted perennials of intermediate ecologic status																
Eragrostis curvula	26.5	41.5	17.0	16.5	21,0	16,0	14,5	5,5	23,0	30,5	31,5	18,0	28.5	2,0	11,0	9.5
Tufted perennials of low ecologic status																
Eragrostis obtusa	3,0	0,5	9.0	6.0	3.0	1,0	2,0	1,5	1,5	1,5	0,5	-			5.5	0.5
Michrochloa caffra			4.0	4,0	9,5	5,0	1,5	0,5								
Creeping grasses of low ecologic status																
Panicum coloratum	7,0	8,0	15,0	13,0	5,5	6,0	21,0	13,0	5,5	1,5	15,5	4,0	16,5	1,0	3,0	2,0
Cynodon dactylon					7,0	9,0	1,0	1,5			4,0	1,0				
Annual species of low ecologic status																
Aristida congesta	2,5	7,5	2,0	2,5	5,0	3,5	3,0	1,0	5,5	8,0	-	1,0	4,5	-	2,5	1,0
Brachiaria eruciformis	-	0,5	3,5	2,0	5,0	0,5	-	0,5	1,5	0,5	2,5	0,5	2,0	-	3,0	-
Tragus racemosus			0,5	-												
Chloris virgata							0,5	-								
Total basal intercept for 10 m line transect	47,5	78,5	66,5	75,5	84,5	78,5	55,0	33,0	37,0	42,0	56,0	25,5	51,5	3,0	26,0	13,0
Change in total basal intercept	Increase of 65,3%		Increase of 13,5%		Decrease of 9,3%		Decrease of 40,0%		Increase of 13,5%		Decrease of 45,5%		Decrease of 94,2%		Decrease of 50,0%	

Table 2. *Total basal intercept of selected species for all 1989 and 1990 samplings (in centimetres)*

Species	Total basal inter= cept for species		Change in total basal intercept
	1989	1990	
Themeda triandra	379,5	500,0	31,8% increase
Eragrostis curvula	193,0	162,0	16,1% decrease
Eragrostis obtusa	41,5	19,0	54,2% decrease
Panicum coloratum	315,5	246,0	22,0% decrease
Aristida congesta	*90,5*	*27,0*	*20,4% decrease*
Brachiaria eruciformis	*28,5*	*8,5*	*70,2% decrease*

CHAPTER 6

SEMI-ARID AND ARID RANGELANDS: A RESOURCE UNDER SIEGE DUE TO PATCH-SELECTIVE GRAZING

Manuscript accepted for publication in "The Journal of Arid Environments"

SEMI-ARID AND ARID RANGELANDS: A RESOURCE UNDER SIEGE DUE TO PATCH-SELECTIVE GRAZING

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Abstract

The role of patch-selective grazing and subsequent patch-overgrazing in the continued retrogression of semi-arid and arid rangelands is discussed. Patch-overgrazing induces vegetation and habitat retrogression. Patch-overgrazing reduces rangeland productivity, enhances desertification and adversely affects rangeland stability. Low and erratic rainfall aggravates the patch-retrogression. Current management practices do not achieve optimal utilisation of available forage concomitant with resource conservation. Urgent research is needed to devise management strategies to reduce patch-overgrazing in rangelands. If present levels of patch-selective grazing are not reduced substantially, the continued retrogression of semi-arid and arid rangelands will not be halted.

Introduction

Widespread rangeland retrogression continues in the arid and semi-arid rangelands of southern Africa in spite of intensive grazing management and research. Unfortunately the retrogression is not restricted to certain vegetation types, land types or dependent on the type of grazing animal (Personal observation). The continued deterioration of these rangelands is ascribed to patch-selective grazing and subsequent patch-overgrazing. Disproportionate range utilisation is a common and universal phenomenon (Stoddart et al., 1975). In this paper the role of patch-selective grazing and subsequent patch-overgrazing in the continued retrogression of semi-arid and arid rangelands is discussed. Furthermore, the effectiveness of present rangeland management strategies to ensure optimal utilisation of available forage concomitant with resource conservation as well as the reversibility of patch-retrogression are discussed.

The effect of patch-overgrazing on the rangeland ecosystem

Selective utilisation in grazing units results in a micro-pattern in which heavily grazed patches/areas alternate with lightly or ungrazed patches/areas (Bakker et al., 1983). Heavily utilised patches are grazed repeatedly and these patches tend to increase in area and number as patch-overgrazing proceeds (Ring et al., 1985).

Extensive vegetation retrogression occurs in long-term overgrazed patches (Fuls & Bosch, 1990a). Perennial, productive, high ecologic status species are gradually replaced by less productive, low ecologic status species and pioneer species (Fuls & Bosch, 1990a). Low biomass production and water use efficiency characterise these low ecologic status species (Snyman et al., 1980; Le Houerou, 1984). Consequently patch-overgrazing reduces the productivity of rangelands.

Substantial habitat degradation occurs in long-term overgrazed patches. Rainfall effectivity is reduced by as much as 60% in severely overgrazed patches (Fuls & Bosch, 1990a). Subsequently the rangeland water budget is adversely affected by patch-overgrazing and a drier micro-climate is engendered in overgrazed patches. It is concluded that patch-overgrazing contributes significantly to the desertification of semi-arid and arid rangelands.

The stability of the range is adversely affected by patch-overgrazing. Fuls & Bosch (1990b) found that substantial vegetation retrogression occurs in long-term overgrazed patches during below average rainfall years in spite of grazing exclusion. They also indicated that degraded patches expand at the expense of less degraded patches (in semi-arid rangelands) during below average rainfall years.

The influence of rainfall

Due to the low and inconsistent biomass production in low rainfall regions, grazing units have to be large to support livestock herds. The subsequent heterogeneity in vegetation and environment within grazing units enhances patch-selective grazing.

Overgrazed areas seldom have a chance to recover sufficiently before the next grazing onslaught due to frequent dry spells between rainfall events. The adverse impact of dry spells is magnified in overgrazed areas as a result of the drier micro-climate created in these areas.

Heavy thunder-showers, which are characteristic of most semi-arid and arid regions, concomitant with the ecosystem modification in overgrazed patches, induce large scale run-off and catastrophic sediment losses. Consequently heavy downpours contribute to the degradation of patch-overgrazed rangelands and enhance the aridity of overgrazed areas.

Imperfections of present management strategies

The disproportionate utilisation of forage is mostly ignored when stocking rates are determined. At present stocking rates are based on the average basal cover and forage availability of grazing units. In practice, most (if not all) grazing units consist of a mosaic of differentially utilised patches which are in varying range condition with varying forage production.

The adverse effects of the patch-overgrazing phenomenon are aggravated by the preferential grazing of previously utilised patches by livestock (Ring et al., 1985). This implies that overutilised patches will be repeatedly overgrazed until the patches have totally deteriorated. As the patch-retrogression advances in these patches, the grazing pressure on less retrogressed patches increases gradually. Sequential patch-retrogression continues until the whole grazing unit is eventually in a poor condition. This piecemeal eroding of the rangeland forage resource is often a very slow process and is therefore mostly ignored by range managers and scientists alike.

Generally, rangeland managers do not allow for the full recovery of grazed patches before subsequent grazing onslaughts. This leads to the continued and successive re-utilisation of previously utilised patches because livestock will return to previously grazed patches first if they are still discernible (Ring et al., 1985). Low and erratic rainfall makes it extremely difficult to rest grazing units until previously utilised patches have recovered to such an extent that they are no longer discernible.

It is economically unjustifiable to adjust stocking rates according to the forage production of degraded patches in grazing units. Already forage is lost in non-utilised patches. Consequently urgent research is needed to determine management strategies which would ensure minimal patch-overgrazing as well as optimal utilisation of presently undergrazed patches. Current management strategies do not achieve optimal utilisation concomitant with effective resource conservation.

Reversibility of the patch-retrogression

The reversibility of the patch-retrogression will depend on the degree of habitat degradation (Fuls, 1990). In areas where a significant decline in rainfall effectivity has occurred, rest-recovery may take decades. Fuls & Bosch (1990b) indicated that semi-arid vegetation which has retrogressed beyond a threshold of drought resilience can not rest-recover. They are of the opinion that recovery trends due to above-normal rainfall will be reversed during subsequent periods of drought. The chances for rest-recovery will be even more remote in arid areas. Costly mechanical inputs may be necessary to restore degraded areas. It is therefore vital to address the patch-overgrazing phenomenon and subsequent patch-retrogression immediately - prevention is better than cure.

Conclusions

Widespread patch-selective grazing and subsequent patch-overgrazing are regarded as the main causes for the continued retrogression of semi-arid and arid rangelands world-wide. If current levels of patch-overgrazing are not reduced substantially, the continued retrogression of semi-arid and arid rangelands will not be halted. Successful elimination or substantial reduction of differential forage utilisation in semi-arid and arid rangelands will greatly increase livestock production and promote the conservation of rangeland resources.

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CHAPTER 7

THE EFFECT OF NUTRIENT ENRICHED SEDIMENT DEPOSITS ON THE VEGETATIONAL TRAITS OF A PATCH-GRAZED SEMI-ARID GRASSLAND

Manuscript submitted for publication in "Vegetatio"

THE EFFECT OF NUTRIENT ENRICHED SEDIMENT DEPOSITS ON THE VEGETATIONAL TRAITS OF A PATCH-GRAZED SEMI-ARID GRASSLAND

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Keywords: Accelerated secondary succession; Basal cover change; Habitat conditions; Permanent micro-plots.

Abstract

Permanent grazing exclosures were established in semi-arid grasslands to study the successional trends of vegetation of patches representing varying stages of vegetation retrogression. After an exceptionally heavy thunder-shower one research plot was flooded with run-off water from cultivated lands nearby, resulting in the deposition of nutrient enriched sediment in the research plot. The subsequent vegetational trends are compared to vegetational trends of similar patches in a control plot, in the same grazing camp, which was not flooded.

Successional trends were accelerated in the sediment covered micro-plots due to the improvement of habitat conditions. Patches representing severe vegetation retrogression in the sediment covered research plot, in contrast to degraded patches in the control plot, showed the most significant increases in basal cover of high ecologic status grass species. It is concluded that succession towards a more desirable species composition and basal cover could be directed through habitat improvements.

The recorded shift towards dominance of high ecologic status grass species, recorded for both research plots, represent a reversal of semi-arid grassland vegetation retrogression. Future surveys will disclose whether obtained recovery trends

are mere fluctuations due to favourable habitat and/or climatic conditions or the start of a persistent secondary succession process.

Introduction

Sheep grazing in grassland vegetation results in a micro-pattern in which short, heavily grazed areas alternate with taller, lightly grazed or ungrazed patches (Bakker et al. 1983). Heavily utilised patches are grazed repeatedly which results in extensively overgrazed patches (Ring et al. 1985). Vegetation retrogression and habitat degradation occurs in repeatedly overgrazed patches (Fuls & Bosch 1990 (unpubl.)).

Patch-overgrazing is a common phenomenon in the climatic climax grasslands of southern Africa which presents a serious threat to the stability and conservation of the rangeland type (Fuls 1990). Research was initiated in 1988 to monitor long-term rest-recovery trends of differentially grazed patches in order to determine the rate and feasibility of rest-recovery of semi-arid grassland vegetation in varying stages of retrogression. To achieve this, sixteen permanent, fenced-off research plots were established in the 600-650 mm rainfall belt of the climatic climax grasslands of southern Africa at the beginning of 1989. Each grazing exclosure was selected to include a variety of patches representing varying stages of vegetation retrogression.

Rainfall in the climatic climax grasslands of southern Africa is characterised by heavy thunder-showers which are of short duration. During the 1989/1990 rainfall season one grazing exclosure was flooded by run-off water from a nearby cultivated land after an exceptionally heavy downpour. A layer of nutrient enriched sediment, more than 20 mm thick in places, was deposited within the grazing exclosure. This paper reports on the subsequent changes in species basal cover recorded for micro-plots in this grazing exclosure which represent a variety of vegetation retrogression stages. The results are compared to vegetational trends recorded for a nearby grazing exclosure on the same soil type in the same grazing camp. This research plot was not flooded by run-off water from the cultivated land and is therefore regarded as a control plot.

Materials and methods

The two fenced-off 30 x 30 m research plots are located in the Edenville district in the 600-650 mm p.a. rainfall zone of the semi-arid climatic climax grasslands of southern Africa. The research plots were fenced-off in February 1989.

Eight 2x1 m permanent micro-plots were established in each research plot. The micro-plots were established within patches representing varying stages of vegetation retrogression.

A line intercept method was used to record species basal cover in the micro-plots (Canfield 1941; Brown 1954). A metal frame containing 5x2 m steel wire line transects was used for vegetation surveys. The anchor holes of the metal frame correspond with pegs delineating the 2x1 m micro-plots. The anchor holes and pegs in the soil ensure exact spatial resampling in subsequent vegetation surveys.

The first sampling of the permanent micro-plots was done in March 1989 (late summer). The seasonal variation of grassland cover (Morris & Muller 1970) implies that subsequent resampling of micro-plots must be done at comparable stages of the growing season. Therefore resampling of the micro-plots was conducted in March 1990. The data of 1989 and 1990 samplings was compared to assess vegetational traits after twelve months of livestock grazing exclusion. The recorded species were classified according to their ecologic status (Janse van Rensburg 1987; Bosch 1989) to ease interpretation of vegetational trends.

Sediment samples were analysed physically and chemically.

Results and discussion

The rainfall recorded for the twelve months between vegetation surveys was 561,5 mm. Although this is somewhat below the long-term regional average of 602 mm p.a., the rainfall was spread evenly over the rainfall season. On eleven occasions was the rainfall recorded for 24 hours in access of 15 mm.

Substantial increases in total basal cover were recorded for all micro-plots located in the flooded research plot. Total basal cover increases ranged from 30,0% to 124,5% (Table 1A). These increases are due to extensive increases in basal cover of high and mediocre ecologic status tufted perennial grasses. On the other hand total basal cover increases recorded for the control plot were significantly less, ranging from 1,0% to 45,0% (Table 1B). Furthermore, the mean total basal cover increase for micro-plots in the flooded research plot was 67,3% whereas micro-plots of the control plot showed a mean total basal cover increase of 34,3%. These results imply that the flooding and subsequent sediment deposits enhanced successional trends. The accelerated succession is ascribed to the improvement of habitat conditions. Furthermore, the high base saturation of the sediment (Table 2) implies that significant quantities of plant nutrients were imported into the system. O'Brien (1984) reports on a linear correlation between succession rates and improved growth conditions in studies where succession was directed through habitat modifications.

In both research plots, basal cover of low ecologic status tufted perennial grasses, low ecologic status creeping grasses, annual grasses and pioneer grasses decreased in contrast to basal cover of tufted perennial grasses of high and mediocre ecologic status. The recorded shift towards high ecologic status grass species dominance can be regarded as a reversal of retrogressive processes. Previous research in the study area indicated that climatic climax grassland retrogression is characterised by a gradual decrease of high and mediocre ecologic status tufted perennial grasses. These species are progressively replaced by tufted and creeping perennial grass species of low ecologic status. Eventually pioneer and annual grass species dominate the sward (Janse van Rensburg 1987; Bosch 1989).

Although successional trends were greatly enhanced by the nutrient enriched sediment deposits, micro-plots of the control plot also showed increases in total basal cover. In both research plots these increases are the result of increases in basal cover of high and mediocre ecologic status species. The general successional trends recorded are ascribed to well spread precipitation concomitant with grazing exclosure.

The recorded vegetative changes were obtained after one growing season. Subsequent surveys will disclose whether these changes are merely seasonal fluctuations due to favourable moisture regimes or the start of a persistent secondary succession process (Van der Maarel 1988).

Research plot comparisons revealed contrasting vegetation trends with regard to total basal cover increases of micro-plots in patches representing varying stages of retrogression (Table 3). Micro-plots in patches in poor condition located in the sediment covered research plot showed the greatest increases in total basal cover. On the other hand, micro-plots located in patches in poor condition in the control plot showed minor increases in total basal cover whereas those in good condition showed the highest increases in total basal cover (Table 3).

These differences are ascribed to modified habitat conditions, changes in rainfall effectivity and differences in competition for available growth substances. The deposition of nutrient enriched sediment improves growth conditions. The added topsoil improves rainfall effectivity and soil moisture regimes, especially where the sediment covers soil crusts. The more favourable micro-climatic conditions are the result of increased soil infiltration and soil moisture retention (Stallings 1957). Furthermore, plant nutrients were imported into the system. The low basal cover of patches in poor condition presents many niches for colonisation. Seeds were covered with sediment, resulting in enhanced seed germination. Due to a lack of competition for growth substances as well as habitat improvements, seedlings were able to persist and existing plants thrived in these favourable growth conditions. Consequently most significant increases in total basal cover were recorded for degraded patches.

The more moderate increases in total basal cover of micro-plots located in patches in good condition are ascribed to a large-scale enhancement of aerial crown growth of existing large, tufted, perennial grasses, due to improved growth conditions. The subsequent increase in competition for available sunlight probably stimulated further crown growth at the expense of basal, lateral growth. Consequently minor basal increases in tuft sizes occurred. Furthermore, large-scale accumulation of above-ground phytomass would inhibit colonisation of niches between large, tufted perennial grasses due to insufficient sunlight penetration through the crown cover.

The contrasting patch-vegetational trends in the control plot are attributed to variations in rainfall effectivity. Fuls & Bosch (1990 (unpubl.)) conclude that habitat modification occurs in patches in poor condition. A drier micro-climate is created due to a reduction in rainfall effectivity of up to 55%. Therefore vegetation of degraded patches is subjected to adverse micro-climatic conditions. Consequently rest-recovery is greatly inhibited. This fact is substantiated by an increase in basal cover of degraded patches of only 17,3% in spite of deferred grazing and favourable climatic conditions. On the other hand the good rainfall effectivity in patches in good condition ensures that soil moisture regimes are favourable for sustained growth, resulting in significant increases in total basal cover when rested. Furthermore, lateral, basal tuft growth was not restricted, due to large-scale aerial crown growth, as was the case with sediment covered patches in good condition.

Conclusions

The recorded vegetational shift towards dominance of high ecologic status grass species represents a reversal of semi-arid grassland vegetation retrogression. This successional trend was significantly accelerated in the research plot covered by nutrient enriched sediments. The enhancement of secondary succession is ascribed to improved habitat and growth conditions.

Significant vegetation recovery was also recorded in patches in mediocre or good condition in the undisturbed research plot due to favourable precipitation, rainfall effectivity and grazing exclosure. In contrast recovery of retrogressed vegetation in degraded patches was significantly less. This is ascribed to unfavourable growth conditions engendered as a result of habitat modifications in degraded patches. The persistence of the recorded successional trends will be determined in future surveys.

Degraded vegetation of patches in poor condition benefited the most from improved habitat conditions. This implies that mechanical improvement of habitat conditions in degraded semi-arid grassland could be used effectively to direct and accelerate range succession towards a more desired species composition and basal cover.

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Table 1: Species basal cover intercepts (in centimetres) for 1989 and 1990 samplings of micro-plots located in patches in varying range conditions
A: Research plot covered with nutrient enriched sediment

Micro-plot no.	8.2		8.5		8.4		8.8		8.1		8.3		8.6		8.7	
Patch condition	Good		Good		Mediocre		Mediocre		Poor		Poor		Poor		Poor	
Year sampled	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
<u>Species</u>																
High ecologic status tufted perennial grasses																
<u>Themeda triandra</u>	28,0	53,0	43,5	62,0	16,0	27,0	22,0	37,5	7,5	25,5	2,5	6,0	11,5	27,0	3,0	15,5
<u>Cymbopogon plurinodis</u>															–	2,0
Mediocre ecologic status tufted perennial grasses																
<u>Eragrotis curvula</u>	43,0	62,0	15,0	36,5	17,0	55,0	2,5	6,5	1,0	3,0	6,5	23,5	–	4,0	0,5	–
<u>Setaria sphacelata</u>			7,5	1,5	1,5	2,5										
Low ecologic status tufted perennial grasses																
<u>Microchloa caffra</u>	0,5	–	16,5	6,0	7,5	1,0			–	1,0	–	1,0	2,0	0,5	1,0	–
Low ecologic status creeping grasses																
<u>Eragrostis lehmanniana</u>	1,0	–					3,0	4,0	19,0	18,5	–	2,0	4,0	10,0	0,5	2,0
<u>Cynodon dactylon</u>			0,5	1,5	5,5	5,0					0,5	5,5			0,5	0,5
Annual pioneer grasses																
<u>Aristida congesta</u>	5,0	0,5	–	0,5	3,5	2,0	6,5	3,5	10,5	7,0	16,5	8,0	0,5	–	6,5	7,0
<u>Tragus berteronianus</u>											0,5	–			2,5	–
<u>Urochloa panicoides</u>							0,5	–			–	0,5	0,5	–		
<u>Chloris virgata</u>							0,5	–								
Total basal cover	77,5	115,5	83,0	108,0	51,0	92,5	35,0	51,5	38,0	55,0	26,5	46,5	18,5	41,5	14,5	27,0
Change in total basal cover (%)	+ 49,0		+ 30,0		+ 81,5		+49,0		+44,5		+75,5		+124,5		+86,0	

Table 1B: Research plot not covered with nutrient enriched sediment

Micro-plot number	9.2		9.8		9.1		9.4		9.7		9.3		9.5		9.6	
Patch condition	Good		Good		Mediocre		Mediocre		Mediocre		Poor		Poor		Poor	
Year sampled	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Species																
High ecologic status tufted perennial grasses																
Themeda triandra	22,5	44,0	20,5	54,5	9,0	24,5			8,5	18,5	9,0	14,5			4,0	7,0
Mediocre ecologic status tufted perennial grasses																
Eragrostis curvula	12,5	15,0	8,5	6,5	14,0	14,0	23,5	37,5	8,0	11,5	9,0	12,5	3,5	10,0	12,0	16,5
Panicum stapfianum					1,0	-			1,0	2,0					5,0	5,5
Aristida bipartita			-	1,0	3,5	7,0	1,5	4,0	2,5	6,0					0,5	1,5
Setaria sphacelata	0,5	-														
Low ecologic status tufted perennial grasses																
Eragrostis obtusa	0,5	-			1,5	-			1,0	-						
Eragrostis plana															4,0	9,0
Microchloa caffra									-	1,5						
Low ecologic status creeping grasses																
Eragrostis lehmanniana	6,5	3,5	4,0	2,5	6,0	3,0	6,5	5,5	5,5	4,0	6,5	4,5	11,5	18,5	7,5	7,0
Sporobolus iocladus	3,5	2,5	1,0	0,5	7,5	2,0	3,5	1,0	8,0	3,0	3,5	2,5	31,0	17,5	0,5	0,5
Cynodon dactylon			-	0,5	-	1,0	0,5	0,5	0,5	2,5			0,5	-	2,0	1,5
Digitaria argyrograpta			2,0	-											0,5	-
Annual pioneer grasses																
Aristida congesta	0,5	-	0,5	-	3,0	3,5	4,0	4,5	4,5	5,5	0,5	-			1,5	2,5
Aristida canescens													1,5	2,5	1.0	-
Brachiaria eruciformis							-	0,5							1,0	-
Total basal cover	44,5	64,5	36,5	65,5	45,5	55,0	39,5	53,5	38,5	54,5	29,5	36,0	48,0	48,5	39,5	51,0
Change in total basal cover (%)	+45,0		+79,5		+21,0		+35,5		+41,5		+22,0		+1,0		+29,0	

Table 2: Sediment analysis

Sample depth (mm)	0-15
Sand (%)	48,1
Silt (%)	22,7
Clay (%)	29,2
Ca (me/100g)	3,68
Mg (me/100g)	2,36
K (me/100g)	1,59
Na (me/100g)	0,14
P (me/100g)	0,79
pH (H_2O)	5,4
pH (KCl)	4,5
CEC[1] (me/100g)	6,47
Base saturation (%)	120,1

[1]CEC = Cation exchange capacity

Table 3. Mean basal cover increases of patches in varying range conditions

	Basal cover increases (%)	
Patch condition	Sediment covered research plot	Research plot not co= vered with sediment
Good	39,5	62,3
Mediocre	64,3	32,7
Poor	82,6	17,3

CHAPTER 8

EVALUATING THE INFLUENCE OF HABITAT CONDITION ON RANGE= LAND RECOVERY TRENDS DURING LONG PERIODS OF REST

Manuscript submitted for publication in "The Journal of the Grassland Society of Southern Africa"

EVALUATING THE INFLUENCE OF HABITAT CONDITION ON RANGE=LAND RECOVERY TRENDS DURING LONG PERIODS OF REST

'N EVALUASIE VAN DIE INVLOED VAN HABITATTOESTAND OP WEIVELDHERSTEL GEDURENDE LANG RUSPERIODES

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Additional index words: basal cover, climatic climax grassland, micro-plots, patches, rainfall effectivity, range condition, rest-recovery, retrogression

Abstract

Soil wetness variations between micro-plots subjected to identical environmental conditions and inputs were used to assess the degree of habitat degradation. Long-term monitoring of basal cover changes in fenced-off micro-plots, representing different stages of vegetation and habitat retrogression, disclosed that the success of rest-restoration is dependent on the condition of the range habitat. Results indicate that habitat degradation precedes vegetation retrogression. Consequently the following hypothesis is postulated: The rangeland habitat is more sensitive to mismanagement than the rangeland vegetation.

The habitat condition of the rangeland has to be assessed simultaneously with other relevant rangeland condition attributes to ensure that range condition assessments are a true reflection of the actual condition of the range.

Uittreksel

Grondvogvariasies tussen mikro-persele onderhewig aan identiese omgewingstoestande en -insette is gebruik om die mate van habitatdegradasie vas te stel. Langtermyn monitering van veranderinge in basale bedekking in afgekampte mikro-persele, wat verteenwoordigend is van verskillende stadiums van plantegroei- en habitatagteruitgang, het getoon dat die sukses van weiveldherstel afhanklik is van die habitattoestand. Resultate dui daarop dat habitatdegradasie plantegroeiretrogressie voorafgaan. Die volgende hipotese word gevolglik gepostuleer: Die weiveldhabitat is meer sensitief vir wanbestuur as die weiveldplantegroei.

Die habitattoestand moet tesame met ander relevante veldtoestandkenmerke bepaal word. Sodoende word verseker dat die bepaalde weiveldtoestand 'n betroubare weergawe is van die werklike toestand van die weiveld.

Introduction

Overgrazing and mismanagement result in the deterioration of the vegetation and habitat of rangelands (Stallings, 1957; Johnston _et al_., 1971; Stoddart _et al_., 1975). The result of rangeland ecosystem retrogression is a reduction in rainfall effectivity (Fuls & Bosch, 1990). The adverse climatic conditions engendered in overgrazed areas, concomitant with a poor water use efficiency of lower ecologic status species which colonise the overgrazed areas (Snyman _et al_., 1980), result in substantial reductions of grazing capacity (Roux & Vorster, 1983). To improve the grazing capacity, and for the establishment of pre-defoliation reserve levels after a severe grazing onslaught, extended periods of rest are commonly incorporated into management strategies. As yet no research has been conducted to evaluate the influence of habitat condition on rest-recovery trends during long periods of rest. Consequently a study was launched in 1988 to assess the rate and feasibility of rest-recovery in a variety of patches representing varying stages of habitat degradation. If rest-recovery is significantly impeded by detrimental changes in habitat condition, it would have serious management implications.

Study Area

The research was conducted in the 600-650 mm per annum rainfall belt in the central part of the semi-arid climatic climax grasslands of southern Africa (Figure 1). The vegetation is described by Acocks (1988) as Cymbopogon-Themeda grassland. Rainfall is erratic, consisting mainly of heavy thunder-showers of short duration which are restricted to the warm summer months (Anonymous 1984). The area is underlain by shale, sandstone and mudstone. Crests and scarps occur on dolerite and sandstone with mid-slopes and footslopes predominantly on mudstone and shale. The topography is undulating to flat. More than 70% of the terrain consists of pediments (Scheepers et al. 1984). Consequently the study reported on here was restricted to the pediments.

Materials and Methods

The research was conducted on four soil types, namely Bonheim, Swartland, Avalon and Glenrosa (Macvicar et al., 1977).

A 30x30m research plot on each soil type was fenced off in February 1989. Each research plot was selected to include a variety of patches representing varying stages of rangeland retrogression induced by patch-overgrazing. Four 2x1m permanent micro-plots were established in each research plot. The micro-plots were located in patches representing varying stages of vegetation and habitat retrogression.

A line intercept method was used to record species basal cover in the micro-plots (Canfield, 1941; Brown, 1954). A metal frame containing 5x2m steel wire transects was used for vegetation surveys. The anchor holes of the metal frame correspond with pegs delineating the 2x1m micro-plots. The anchor holes and pegs in the soil ensure exact spatial resampling in subsequent vegetation surveys.

The first sampling of the permanent micro-plots was done in March 1989 (late summer). The seasonal variation of grassland cover (Morris & Müller, 1970) implies that subsequent resamplings of the micro-plots must be done at comparable stages of the growing season. Therefore the first resampling of the micro-plots was conducted in March 1990.

The range condition assessment module of the PUK model for grassland dynamics, a reciprocal averaging technique (Hill, 1973), was used to assess the range conditions for the micro-plots (Bosch _et al_., 1988, Bosch _et al_., 1989).

Before the importance and influence of habitat condition in rest recovery trends could be assessed, a method had to be devised to establish the degree of habitat retrogression (habitat condition) objectively. Soil wetness variations between micro-plots in a specific grazing exclosure were used as habitat condition indices. This practice can be justified by the following reasoning: The amount of moisture present in the soil at a specific site, at a given moment, is determined by a variety of biotic and abiotic factors, e.g. rainfall, temperature, radiation, air convections, topographical and soil characteristics, vegetation type and cover, evapotranspiration, soil compaction and crusting, infiltration, run-off and erosion. If the long-term average soil wetness declines at a specific site in spite of unchanged environmental inputs (precipitation, radiation, wind, temperature), it is regarded as a reduction in rainfall effectivity. The reduction in rainfall effectivity is the result of detrimental habitat changes, e.g. soil compaction and crusting, reduced infiltration and increased run-off (Fuls & Bosch, 1990). Consequently, significant differences in soil wetness between sites which are subjected to similar environmental conditions and inputs over time are attributable to differences in habitat condition. Because the four micro-plots in each grazing exclosure are subjected to identical environmental inputs, differences in soil wetness were regarded as differences in rainfall effectivity brought about by differences in habitat condition.

Soil wetness of test areas was recorded as follows: Three soil samples were collected on 28 November 1989, 9 January 1990 and 12 March 1990 respectively at each respective micro-plot. These soil samples were extracted 150mm away from the micro-plot boundaries, on the outside, and the holes filled up afterwards to ensure minimal disturbance in or around the research plots. On each occasion the three soil sampling sites were spaced evenly around the respective micro-plots. The soil samples were extracted to a depth of 200mm, using a soil auger with a 30mm diameter. It is argued that the wetness of the upper 200mm of the soil is primarily influenced by variations in rainfall effectivity whereas soil wetness at depth is increasingly influenced by the water-table, long-term annual precipitation and redistribution of subsoil moisture. The soil samples were sealed in airtight containers to prevent moisture losses due to evaporation. The respective gravimetric soil moisture contents of these soil samples were established according to the method described by Hillel (1982).

Results and Discussion

Soil wetness varied as much as 60% between micro-plots in a research plot (Table 1). Since the environmental inputs at a 0,009 ha research plot are similar for all micro-plots in that plot, it can be accepted that differences in soil wetness are the result of differences in rainfall effectivity and therefore differences in habitat condition.

The detrimental effect of habitat degradation on rest-recovery is illustrated by the continued retrogression, in spite of livestock exclusion, in micro-plots where rainfall effectivity (habitat condition) was poor, e.g. micro-plots 1.2, 1.3, 2.2, 3.1, 3.2, 4.1 and 4.2 (Table 1). In contrast vegetation cover increased substantially in nearby micro-plots where rainfall effectivity (habitat condition) was good, e.g. 1.1, 2.3, 3.3 and 3.4 (Table 1). All differences in vegetational trends recorded in the respective research plots can be attributed to variations in soil moisture regimes prevalent at micro-plot sites. These results indicate that rest-restoration of rangelands is dependent on the condition of the range habitat. As long as habitat conditions are favourable, long-term resting of rangeland will result in significant increases in basal cover (Table 1). However, in grazing camps where serious habitat retrogression has occurred, long term resting may not facilitate a return to pre-defoliation reserve levels or bring about a significant improvement in range condition. It is therefore imperative that management strategies must be adjusted to preserve the habitat in order to ensure long-term productivity. Thurow et al. (1984) conclude that the long-term success of rangeland management is dependent on its ability to maintain or improve the hydrology and soil conditions of the range.

The continued vegetation retrogression in micro-plots deferred from grazing is ascribed to habitat modifications prior to livestock exclusion. This implies that habitat degradation preceded vegetation retrogression. This conclusion is substantiated by the findings of Fuls & Bosch (1990). They indicated that after an initial decline in basal cover of desired species, induced by excessive grazing of grass species intolerant to over-utilisation, vegetation retrogression lags behind habitat retrogression.

Excessive removal of crown cover results in the direct impact of raindrops onto the bared soil surface between tufts.

Consequently soil surface crusting occurs, resulting in reduced infiltration rates (Stallings, 1957). Furthermore, overgrazing is accompanied by enhanced soil compaction caused by livestock trampling. Research disclosed that one season of overgrazing and excessive trampling results in substantial reductions in rainfall infiltration as well as increased soil compaction (Achouri & Gifford, 1984; Abdel-Magid et al., 1987). It is argued that the perennial vegetation would react to decreases in rainfall effectivity only some time after a substantial decline in rainfall effectivity has occurred. The above reasoning, concomitant with previous findings by Fuls & Bosch (1990), prompts the formulation of the following hypothesis: The rangeland habitat is more sensitive to mismanagement than the rangeland vegetation. Vegetation, especially perennial species, react to detrimental changes in the habitat only after significant habitat retrogression has occurred. Consequently vegetation retrogression lags behind habitat retrogression.

The sensitivity of the rangeland habitat to mismanagement implies that management strategies have to be evaluated firstly with regard to their ability to preserve the habitat. By the time that the vegetation reflects mismanagement, serious habitat retrogression may have already occurred which will hamper prospects of effective rest-restoration.

The range condition assessments given in Table 1 are based only on the species composition of the micro-plots. No habitat data was incorporated in the calculations of range condition.

These range condition assessments imply that micro-plot 1.3 is in a much better condition than micro-plot 1.2 (Table 1). However, significant vegetation retrogression occurred in micro-plot 1.3 whereas an increase in basal cover of perennial grasses was recorded for micro-plot 1.2. Similar contrasting trends of severe vegetation retrogression in patches in better range condition, compared to increases in basal cover of perennial grasses in patches in lesser condition, was obtained for micro-plots 3.1/3.4 and 4.1/4.4 respectively (Table 1). These vegetation trends, concomitant with more favourable moisture regimes obtained for micro-plots 1.2, 3.4 and 4.4, disclose that these plots are actually in better overall range condition than micro-plots 1.3, 3.1 and 4.1 respectively. These results illustrate the imperfection of defining range condition wholly on the basis of species composition. The overall variation between habitat condition and range (actually vegetation) condition (Table 1) implies that the range (vegetation) condition assessment procedure employed is a poor indice of habitat condition. Wilson (1984) states that changes in soil attributes are of primary importance in rangeland condition assessments. Wilson and Tupper (1982) conclude that range condition cannot be adequately defined from vegetation measurements alone. Therefore rangeland condition indices which do not include habitat condition assessments present an inaccurate reflection of the "state of health" of the rangeland ecosystem.

In spite of considerable differences in soil characteristics between the soil types chosen for the research, a similar trend of rainfall effectivity reduction, as habitat degradation proceeds, was obtained (Table 1). These results indicate that the detrimental effects of overgrazing on habitat condition, and subsequent rest-recovery prospects, are not exclusive to specific soil types or soil characteristics.

The vegetation retrogression in degraded patches was obtained in research plots deferred from grazing. It is argued that the detrimental effect of habitat retrogression on rangeland vegetation would be significantly enhanced if grazing stress, or any environmental stresses, were to be introduced into the system.

Conclusions

* Habitat condition governs rangeland vegetation trends.

* If the habitat is allowed to deteriorate significantly, effective range-restoration will not be possible through extended periods of rest alone but will require mechanical inputs to improve the range significantly.

* The range habitat is more sensitive to mismanagement than the vegetation - at least at some stages of rangeland retrogression.

* Management strategies should be evaluated according to their ability to preserve the range habitat.

In the light of the above, it is regarded as essential for optimal biomass production and resource conservation that range management should be much more orientated towards habitat conservation and improvement than is presently the case.

The habitat condition of the rangeland has to be assessed simultaneously with other relevant rangeland condition attributes to ensure that range condition assessments are a true reflection of the actual condition of the range.

Soil moisture recordings can be used effectively to determine rainfall effectivity variations between sites subjected to similar environmental conditions and inputs. Furthermore, rainfall effectivity comparisons between such sites will disclose the habitat condition of a site relative to other sites.

Acknowledgement

The comments and financial assistance of Prof. O.J.H. Bosch are much appreciated.

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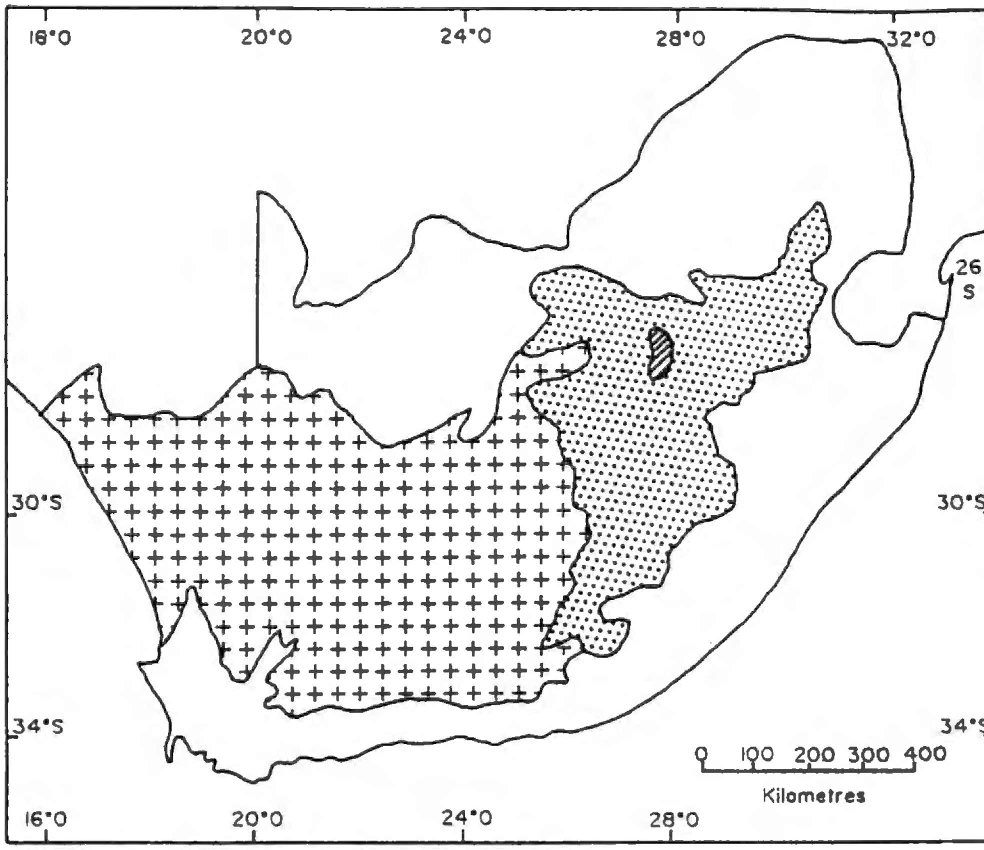
Caption for Figure

Fig. 1. The study area in the semi-arid climatic climax grasslands of southern Africa



LEGEND

Arid Karoo biome

Semi-arid climatic climax grasslands

Study area

Table 1. Soil wetness, range condition and basal cover changes recorded in the research plots

Soil type	Micro-plot no.	Average gravimetric soil moisture content (%) — Sampling date: 28/11/89	9/1/90	12/3/90	Range condition (%) 1989	1990	Basal cover (%) 1989	1990	Change in basal cover (%)	Change in basal co= ver of perennial grasses (%)
Bonheim	1.1	12.5	15.9	16.9	43.5	54.0	5.0	6.6	+32.0	+29.2
	1.2	6.8	14.1	9.4	18.6	25.9	4.6	3.9	-15.2	+ 7.9
	1.3	5.0	10.5	7.9	31.2	18.1	4.1	2.3	-43.9	-38.2
	1.4	5.3	13.5	10.2	30.6	29.9	3.6	3.6	0	+16.6
Avalon	2.1	3.8	10.8	5.0	37.8	39.1	8.9	10.3	+15.7	+37.3
	2.2	3.6	10.7	4.8	51.4	50.4	9.3	9.2	- 1.1	+ 3.0
	2.3	5.5	13.2	7.0	49.6	51.2	6.7	8.9	+32.8	+33.1
	2.4	3.3	9.9	4.0	50.6	51.3	4.4	4.6	+ 4.5	+15.2
Swartland	3.1	3.1	5.7	5.2	53.1	51.2	6.3	3.4	-46.0	-45.1
	3.2	3.2	6.5	5.6	47.8	46.3	5.7	4.0	-29.8	-35.0
	3.3	4.9	13.1	11.7	45.6	49.9	7.7	9.6	+24.7	+34.8
	3.4	4.4	12.5	11.7	44.8	54.5	7.7	9.3	+20.8	+44.8
Glenrosa	4.1	2.9	6.4	2.8	37.8	35.7	1.7	0.9	-47.1	-45.8
	4.2	4.9	7.4	3.9	43.6	44.1	2.7	2.3	-14.8	-13.0
	4.3	7.1	12.1	5.9	52.9	53.9	3.9	3.8	- 2.6	+ 8.9
	4.4	5.1	7.4	4.1	32.6	41.2	2.6	2.4	- 7.7	- 2.7

CHAPTER 9

A TECHNIQUE FOR OBJECTIVE HABITAT CONDITION ASSESSMENTS IN RANGELANDS

Manuscript accepted for publication in "The Journal of Arid Environments"

A TECHNIQUE FOR OBJECTIVE HABITAT CONDITION ASSESSMENTS IN RANGELANDS

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Abstract

An objective habitat condition assessment technique is proposed which is based on calculations of similarity between rainfall effectivity (displayed in soil wetness) of reference and test areas subjected to the same environmental conditions and inputs. If this habitat condition assessment technique is used concomitant with vegetation condition assessments, the overall "state of health" of the rangeland ecosystem can be evaluated more accurately. Objective habitat condition evaluations would help to direct rangeland management strategies towards achieving optimal utilisation concomitant with resource conservation.

Introduction

Generally, range condition is defined by indices of vegetation change based on vegetation composition measurements (Tainton *et al.*, 1980; Vorster, 1982; Mentis, 1983; Heard *et al.*, 1986; Bosch *et al.*, 1988; Bosch *et al.*, 1989). The imperfection of this practice is addressed by Wilson (1984) who clearly states that changes in vegetation composition can not be used as an absolute measure of range condition. Soil stability is considered to be of greater importance than productivity or vegetation change in range condition evaluations (Wilson & Tupper, 1982). Furthermore, Fuls (1990) concluded that the habitat is in some instances more sensitive to mismanagement than the vegetation. This inference implies that by the time vegetation retrogression reflects habitat changes, serious habitat degradation may have already occurred.

At present habitat condition assessments are principally based on estimates of the extent of erosion (Tainton *et al.*, 1980; Wilson & Tupper, 1982; Wilson, 1984). This habitat condition assessment technique is insensitive to initial habitat changes because extensive erosion is preceded by various other detrimental habitat changes, e.g. soil crusting, increased run-off (Fuls & Bosch, 1990). Consequently, habitat degradation may have advanced significantly by the time that erosion is readily detectable.

Generally, the condition of the range habitat is assessed by subjective ratings (Wilson & Tupper, 1982). Foran et al. (1978) proposed a technique where changes in basal cover were used to evaluate habitat condition and trends more objectively. However, Tainton (1988) considers basal cover measurements as too unreliable to be used effectively in range condition assessments.

To date the lack of an objective habitat condition assessment technique, which is both practical and effective, still hampers range condition evaluations. A study, which was launched to assess the influence of habitat degradation on rest-recovery of rangelands (Fuls, 1990), revealed that soil wetness recordings can be used effectively to determine rainfall effectivity changes at a specific site. The rainfall effectivity of a site was defined by the comparative soil wetness between the test area and a reference area, in the immediate proximity of the test area, subjected to the same environmental conditions and inputs. Consequently, a habitat condition assessment technique is proposed which is based on calculations of similarity between rainfall effectivity of reference and test areas subjected to similar environmental conditions and inputs.

Habitat condition assessment technique

Background theory

As yet no acceptable objective habitat condition assessment technique exists. It is therefore not possible to compare/evaluate the technique against an existing norm or standard. Consequently, it is argued that the technique must be weighed against the scientific soundness of reasoning which gave rise to the technique. The technique is based on the following principles:

The amount of moisture present in the soil at a specific site, at a given moment, is determined by a variety of biotic and abiotic factors to which the site is subjected over time. The biotic factors include vegetation type and cover, grazing, trampling and the action of soil microflora and -fauna. The abiotic factors include precipitation, evapotranspiration, temperature, radiation, air convections, topographical and soil characteristics, soil compaction and crusting, infiltration, run-off and erosion. If the long-term average soil wetness declines at a specific site in spite of unchanged environmental inputs (precipitation, radiation, wind, temperature), it is regarded as a reduction in rainfall effectivity (Fuls, 1990). The reduction in rainfall effectivity is the result of detrimental habitat changes, e.g. soil compaction and crusting, reduced infiltration and increased run-off. Consequently, significant differences in soil wetness between sites which are subjected to similar environmental conditions and inputs over time are attributable to differences in habitat condition.

Homogeneous grazing units are not grazed uniformly by livestock but rather in small to large patches (Bakker *et al.*, 1983). As a result of patch-grazing, most (if not all) range grazing units contain areas which are not utilised or are sparsely utilised. These patches are regarded as habitat condition bench-marks or reference sites in which the habitat is well preserved.

The grazing unit in which the condition of the habitat is to be assessed, has to be homogeneous with regard to environmental conditions and inputs. Significant variations in environmental conditions will reduce the reliability of assessments considerably or will necessitate an impractical number of samplings.

Field procedures and data interpretation

The first step is to identify representative bench-mark patches in the grazing unit where the habitat condition assessment is to be conducted. The optimal number of bench-marks (at least three) will depend on the size of the grazing unit, homogeneity of vegetation, homogeneity of environmental conditions (e.g. soil depth, slope), the accuracy required and the time available. To minimise the influence of time-related soil moisture variations, it is imperative that all soil samples are extracted the same day. The selected reference sites must be representative of the best range condition, with regard to both habitat and vegetation, encountered in, or desired for, the specific grazing unit.

Data are collected as follows:

(a) On a random sampling basis, at least three soil samples (the optimum number will depend on the size of the bench-mark, homogeneity of environmental conditions and vegetation in the bench-mark, accuracy required and the time available) are extracted from inside each bench-mark site. All soil samples are extracted to a depth of 200 mm, using a soil auger. It is argued that the wetness of the upper 200 mm of the soil is primarily influenced by variations in rainfall effectivity whereas soil wetness at depth is increasingly influenced by the water-table, long-term annual precipitation and redistribution of subsoil moisture. It was found that a soil auger with a 30 mm diameter is ideal for soil sampling. Such a soil auger extracts a soil sample of approximately 300 g (200 mm depth).

(b) As a guide-line, it is proposed that at least five soil samples (the optimum number will depend on the size of the grazing unit, homogeneity of environmental conditions and vegetation in the grazing unit, accuracy required and the time available) must be extracted from the grazing unit for each bench-mark, e.g. if four bench-marks are selected, twenty soil samples must be taken from the test area. A random sampling procedure must be employed and the sampling sites must be spread evenly over the whole test area.

(c) The respective soil samples are collected and stored in airtight containers to prevent evaporation.

(d) The gravimetric soil moisture content of each soil sample is determined as described by Hillel (1982).

The mean soil wetness of the test area is compared to the mean soil wetness recorded for the reference sites. Such a similarity index will disclose the extent of rainfall effectivity decrease in the grazing unit or test area. In this way the condition of the range habitat, relative to the optimum or desired habitat condition, can be evaluated.

Test example

The feasibility of this technique was tested in two homogeneous grazing units which are similar in size (approximately 40 ha). Three bench-marks (located in under-utilised patches) and fifteen test area samplings were used respectively. The results are presented in Table 1. Approximately four man-hours were required for the field work in each grazing unit.

The range condition score, based on species composition (modified quantitive climax method (Tainton et al., 1980)), implies that both grazing units are in similar condition (Table 1). If rainfall effectivity measurements are included in the evaluation of the condition of the grazing unit, it is clear that substantial habitat degradation has occurred in grazing unit 1 (Table 1). Consequently, the long-term productivity and stability of this grazing unit are endangered if grazing strategies are not adjusted substantially. By comparison, grazing unit 2 requires less significant management adjustments to facilitate a return to a more desired species composition and basal cover.

It is concluded that objective habitat condition assessments, conducted concomitant with vegetation condition assessments, will facilitate more accurate evaluations of the overall condition of rangeland ecosystems. This in turn will help to direct management strategies towards achieving maximum biomass production and optimal utilisation concomitant with effective resource conservation.

Acknowledgement

The financial support provided by Prof. O.J.H. Bosch is much appreciated.

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Table 1. Average soil wetness recorded for reference and test areas in two homogeneous grazing units to assess changes in rainfall effectivity (habitat condition)

Grazing unit no.	Average gravimetric soil moisture content (%): Reference area (Benchmarks)	Average gravimetric soil moisture content (%): Test area (Grazing unit)	Rainfall effectivity (habitat condition) (%) (Benchmark = 100%)	Range con= dition (%) (Based on species composition)
1	16.4	11.1	67.7	61
2	11.9	10.4	87.4	68

CHAPTER 10

VIEWPOINT: RANGE CONDITION - A MISUNDERSTOOD CONCEPT

Manuscript submitted for publication in "The Journal of Range Management"

VIEWPOINT: RANGE CONDITION - A MISUNDERSTOOD CONCEPT

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Abstract

At present range condition assessments are incorrectly based on vegetation attributes. Vegetation attributes should merely be used as indices of forage value and therefore rangeland productivity. Soil condition and range hydrology assessments should be used as absolute measures of range condition. Once the focus of range condition assessments is shifted from the vegetation to soil condition and range hydrology, a universal range condition assessment technique is within reach of range scientists.

Wilson (1984) summarised the long standing, general viewpoint of range scientists and range managers with regard to range condition and range condition assessments as follows: Since changes in the vegetation may both precede and reflect changes in other attributes, it is convenient in survey situations to merely measure vegetation. For decades, the general acceptance of this viewpoint formed the underlying philosophy in all attempts to devise measurement systems that will quantify rangeland condition changes objectively. The search was on, and is still on, for objective rangeland condition assessment techniques based entirely on vegetation attributes (e.g. composition, cover, biomass, palatability, ecologic status of species).

The reasoning behind the range condition concept as it stands at present is seriously questioned in this paper. It is proposed that soil condition and range hydrology define the actual condition of the range whereas vegetation attributes merely define productivity and forage value. This viewpoint is substantiated by Wilson (1984) who states that if the range habitat is stable, changes in rangeland vegetation should be assigned a value only in terms of their consequence for long-term productivity.

As early as 1951 Ellison et al. (1951) argued that range condition should be based primarily on soil stability and only secondarily on vegetation attributes. Smith (1978) considered the state of the soil as an absolute measure of range "health".

Wilson and Tupper (1982) concluded that the importance of soil stability is greater than productivity, which in turn is more important than vegetation change.

Is it not true that soil condition and range hydrology primarily influence rangeland vegetation trends? Is it not a fact that the encountered vegetation attributes in rangelands are primarily the consequence of soil and hydrology influences? Vegetation changes are more often than not merely a reflection of changes in soil condition and range hydrology. Fuls (1990a) concludes that the soil and the range hydrology are more sensitive to mismanagement than the vegetation. This conclusion implies that vegetation changes cannot be used as an early warning system against rangeland retrogression. By the time that the vegetation indicates any major impact on soil condition and range hydrology, serious edaphic retrogression may have already occurred. Significant changes in soil condition and range hydrology are often only reversible at great cost and at best result in serious reductions in biomass production. This fact underlines the necessity of addressing the misconception of using vegetation attributes to evaluate range condition and trend.

Thurow et al. (1984) state that the long-term success of rangeland management is dependent on its ability to maintain or improve the hydrology and soil conditions of the range. This implies that management strategies should be evaluated firstly according to their ability to preserve the range hydrology and soil condition. As yet only one practical, objective range hydrology and soil condition assessment technique has been presented (Fuls 1990b) whereby the impact of management strategies on range hydrology and soil condition could be evaluated. Assessments are done by simply comparing the rainfall effectivity of maintained reference sites (representing optimal rainfall effectivity) with those of test areas subjected to similar environmental conditions and inputs.

In the light of the above it can rightly be asked: Why, in the continuous search for measurement systems that will quantify rangeland ecosystem changes, has not more research effort been devoted to the construction of objective range condition assessment techniques based on soil and hydrology attributes? All effort has gone (incorrectly!) into the construction of vegetation condition assessment techniques which should be merely employed as indices of productivity and forage value (but were not compiled with this purpose in mind) and not as indices of range condition.

The disadvantages of trying to construct a range condition indice which is based on vegetation attributes are obvious. These include:

* Vegetation is constantly in a state of flux - condition assessment techniques using vegetation attributes therefore have to be updated from time to time (at extra time and cost).

* The pathways of vegetation retrogression and succession are virtually unique for every vegetated square metre.

* It is impossible to construct a universal (or even regional?) vegetation assessment technique due to immense variability in composition (what about ecotypification?) and factors that influence the vegetation. Vegetation dynamics vary substantially on all scales due to numerous environmental parameters, e.g. vegetation composition and cover, season, macro- and micro-topography, macro- and micro-habitat condition, zoological inputs (e.g. grazing, insects), presence of seed, soil characteristics and macro- and micro-climate.

* Vegetation measurements are an unreliable assessment of range hydrology changes and soil condition. No timely warning of range hydrology and soil condition changes is assured.

By comparison there are many advantages of using soil and hydrology attributes as range condition indices:

* Soil and range hydrology changes only vary in tempo and extent. Relevant dynamic processes are predictable and universally the same, e.g. raindrop impact - soil crusting and compaction - decline in rainfall infiltration - enhanced run-off - erosion - decrease in rainfall effectivity. This implies that a universally acceptable range condition assessment technique is a possibility.

* Soils and range hydrology are more constant variables than vegetation. These range attributes are not significantly

influenced by as many environmental parameters as is the case with vegetation.

* Cost effectiveness (baring the prospect of a once-off, universally acceptable range condition assessment technique). Soil condition and range hydrology orientated management ensures long-term productivity. Research can concentrate on improving rangeland productivity whilst the influence of management strategies on soil condition and range hydrology is carefully monitored.

Conclusions

Once a technique exists that can effectively define the condition of the range, and give a timely warning of condition changes, rangeland scientists can devote more of their time on research to improve the productivity of rangelands. After all, the world cannot be fed on range condition assessments. It is the authors opinion that once the focus of range condition assessments is shifted from the vegetation to soil condition and range hydrology, a universal range condition assessment technique is within reach of range scientists. Up to now needless effort and money has been wasted to define ecosystem changes by way of vegetation measurements instead of seeing the rangeland vegetation for what it is: forage. Furthermore, most grazing and management strategies are based on vegetation attribute orientated monitoring and managing philosophies. This does not automatically guarantee optimal soil condition and range hydrology or optimal forage production in the long-term.

Grazing strategies may have to be adjusted to comply with range hydrology and soil attributes in order to achieve optimal utilisation and preservation of rangeland resources. The time has come to draw a clear destinction between forage value (vegetation condition in rangelands *per se*) and actual range condition as defined by soil condition and range hydrology.

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CHAPTER 11

DISCUSSION

DISCUSSION

General aspects

Widespread patch-selective overgrazing in southern Africa, especially in semi-arid and arid regions, contributes largely to the overall retrogression of rangelands in the area. More research is, however, needed to quantify the precise effect thereof and to adapt or devise management strategies to solve the problem. One way of ensuring more even use of forage may be to use chemical treatments to attract grazing animals to under-utilised patches/areas or to discourage re-utilisation of previously overutilised patches in subsequent grazing onslaughts. More research is also needed to evaluate the effect of patch-overgrazing on phytomass and animal productivity. Such data will serve as an incentive for range managers to address patch-overgrazing more specifically than is presently the case.

The fact that degraded patches expand at the expense of less degraded patches in years of below average rainfall, inspite of deferred grazing, poses a serious threat to the preservation of arid and semi-arid rangeland resources worldwide. What is even more disturbing, is the prospect that arid and semi-arid rangelands, which have retrogressed beyond a threshold of resilience to even minor droughts, can not rest-recover due to their susceptibility to unfavourable climatic conditions (Fuls & Bosch, 1990a). Future research must define the exact threshold of drought resilience of the vegetation (excluding catastrophic droughts which would result in extensive retrogression in any case) for different climatic zones, vegetation types and stages of range retrogression. Range managers need to be made aware of such thresholds and subsequently should strive to prevent retrogression beyond such a threshold. Habitat condition monitoring could serve as a timely warning against significant retrogression (Fuls, 1990a) in the attempt to prevent range retrogression beyond the drought resilience threshold. Habitat monitoring concomitant with long-term vegetation monitoring could be used in future research to determine drought resilience thresholds. Semi-arid and arid rangelands which have retrogressed beyond a threshold of drought resilience will have to be restored rapidly by way of mechanical inputs (mechanical breaking of soil crusts, reseeding, chemical manipulation etc.) to prevent catastrophic retrogression due to long dry spells and/or years of below average rainfall.

Mechanical improvement of habitat condition could be used effectively to direct and accelerate range succession towards a more desired species composition, basal cover and phytomass production (Fuls, 1990b). This conclusion is substantiated by previous research conducted by O'Brien (1984). Results obtained also prove that soil condition and range hydrology govern rest-recovery trends in rangelands (Fuls, 1990c). If the habitat is allowed to deteriorate significantly, effective range restoration will be seriously inhibited.

Habitat orientated range monitoring

The long-term range preservation, biomass productivity and financial repercussions due to substantial habitat degradation make it worthwhile to shift the emphasis of range monitoring more towards the habitat. The extent of habitat degradation and rainfall effectivity reduction due to mismanagement also underline the necessity of habitat condition monitoring (Fuls & Bosch, 1990b). Furthermore, results obtained indicate that the range habitat is more sensitive to mismanagement than the vegetation and subsequently precedes vegetation retrogression (Fuls, 1990c; Fuls & Bosch, 1990b). Consequently, monitoring of vegetation attributes will give no timely warning of habitat retrogression due to a time-lag between habitat retrogression and vegetation retrogression. By the time that vegetation retrogression indicates habitat degradation, serious and irreversible damage may have already occurred. It is therefore imperative that habitat monitoring is done on a regular basis in rangelands. This conclusion is substantiated by Hulbert (1978) who states that early detection of change can be achieved by monitoring the soil properties of the range.

The importance of choosing the correct variable to monitor changes and to assess range condition must not be underestimated. This statement is substantiated by two important ecological principles outlined by Holling (1978): Firstly, impacts on the environment are not necessarily immediate and gradual, they can appear abruptly some time after the event. Secondly, monitoring of the wrong variable can seem to indicate no change even when drastic change is imminent. It is concluded that for meaningful ecologic monitoring in rangelands, habitat and vegetation attributes have to be assessed and taken into consideration. For agricultural monitoring in rangelands, habitat and production attributes have to be considered and assessed. In both instances, however, the habitat is regarded as the most important variable to be monitored. Previous research supports this line of thought: As early as 1951 Ellison et al. (1951) argued that range condition assessments should be based primarily on soil stability and only secondarily on vegetation. Wilson & Tupper (1982) regard the importance of soil stability as greater than productivity, which in turn is more important than vegetation change. Smith (1978) concluded that the state of the soil should be used as an absolute measure of range health. Thurow et al. (1984) state that the long-term success of rangeland management is dependent on its ability to maintain or improve the hydrology and soil conditions of the range.

A significant imperfection of using vegetation attributes to define range condition is that once-off vegetation measurements in rangelands do not disclose vegetation trends. It is not possible, by way of snapshot vegetation measurements alone, to determine whether a species composition or vegetation condition score is a remnant of a previously more favourable vegetation condition or the start of a shift towards a more favourable vegetation condition. Such vegetation condition data do not disclose whether succession or retrogression is occurring. In practice this means that a range manager can only rely on long-term vegetation data to direct or evaluate management strategies. However, due to the general ignorance of this problem, range managers often base grazing strategies on once-off vegetation condition assessments. Fluctuations due to, for example, climatic variation could play havoc with range management strategies and preservation efforts if management is based on snapshot vegetation measurements alone. If, however, range hydrology and soil attributes are assessed concomitant with vegetation attributes, a clearer indication of rangeland condition and trends will be obtained. Vegetation condition scores could be qualified as follows: A significantly better vegetation condition score compared to the habitat condition score would indicate that changes in vegetation are imminent if management is not adjusted. Significantly lower vegetation condition scores than habitat condition scores during below-normal rainfall years would indicate that the change in vegetation is not the result of a change in range condition but rather the result of insufficient rainfall. In this way it will be possible to determine whether changes are the result of mere fluctuations or whether a real change in range condition has occurred. However, the use of habitat condition as an absolute indice of range condition is regarded as the most effective way to define the state of health of the range. In the case of habitat condition assessments, management must react to once-off habitat measurements to ensure long-term range stability and preservation. Reliable soil condition and range hydrology measurements can be used effectively on a snapshot basis to direct management strategies because soil condition and hydrology attributes are more constant variables than vegetation attributes. Soil condition and hydrology attributes will not be influenced nearly as significantly by climatic fluctuations, for example, as is the case with vegetation attributes. Vegetation sampling only serves to define the productivity status, conservation status or successional status of the range vegetation. Undoubtedly these aspects are of importance in resource management and preservation but are unreliable indices of range condition.

An important principle originating from this work is the following: Upper layer soil wetness recordings can be used effectively to determine rainfall effectivity variations between sites subjected to similar environmental conditions and inputs (Fuls, 1990c). Consequently, rainfall effectivity comparisons between sites subjected to similar environmental conditions and inputs will disclose the habitat condition of a site relative to other sites. This principle was used in the creation of a technique for objective habitat condition assessments in rangelands. This technique is to serve as the basis from which research must spring forth to adapt and or improve the technique according to specific needs or conditions encountered in the field. The number of samples and bench-marks to be used in habitat condition assessments can not be defined rigidly due to the diversity and uniqueness of vegetation worldwide. Further research will undoubtedly improve the apparatus/methods used and the application of the technique presented. The principle is regarded as more important than the exact application of the technique as presented at this stage. This technique could serve as an incentive for intensive research to address and streamline the use of habitat condition and rainfall effectivity in range condition assessments worldwide. Shortcomings which have to be addressed are the following: (a) The influence of transpiration by plants and evaporation of rainfall (retained on above-ground plant material) from bench-mark sites on soil wetness must be quantified. At this stage it is assumed that the effect of denudation, soil crusting and overall decline in habitat condition on range hydrology dwarfs the influence of transpiration and rainfall evaporation. To what extent is this assumption correct? How can the influence of transpiration and rainfall evaporation be incorporated into the habitat condition assessment technique to improve the reliability thereof? How does this effect differ for different vegetation types and how does the structure of the vegetation influence soil moisture variations due to transpiration and rainfall evaporation?

(b) Another challenge is to devise an equation whereby the differences in soil moisture due to climatic variation over time can be evened out. As it stands now, meaningful long-term comparisons can only be made if subsequent assessments are conducted at stages when the soil wetnesses of reference sites are similar to those obtained for previous measurements.

A new range management philosophy

Generally, range philosophies in southern Africa can be grouped into two distinct schools of thought. Firstly there is an agronomically based school of thought. The basic range management philosophies and range research conducted are biomass productivity orientated. The emphasis falls premost on animal productivity. Vegetation attributes are regarded as important only insofar they influence animal productivity. Habitat attributes are given little consideration. The success of management strategies is evaluated according to animal productivity. If vegetation attributes give an unreliable indication of habitat changes and range condition, what reliability has animal productivity as an indice of habitat changes and range condition?

Secondly, there is an ecologically based school of thought. Range management philosophies and range research are based primarily on vegetation attributes. On a relatively small scale, compared to vegetation attributes, various environmental and animal attributes are incorporated into the system to help define vegetation trends and to direct management strategies. Habitat attributes are regarded as important only insofar they influence range vegetation trends.

As a direct result of these animal and vegetation biased schools of thought, habitat management and research lags far behind in priority and status in southern Africa. These circumstances and the results obtained in this study, concomitant with supportive literature, merit a drive for a habitat orientated school of thought. In such a school of thought the emphasis in range management philosophies and range research will fall firstly and foremost on range soil and hydrology attributes, only secondarily on vegetation attributes and thirdly on animal attributes. Does the habitat not sustain the range vegetation which in turn sustains the range animal? Which one is subsequently of greater importance in the range ecosystem? If the habitat is well preserved, long-term optimal biomass productivity is ensured. Surely optimal rainfall effectivity is a prerequisite for optimal biomass production. Habitat (range hydrology and soil condition) orientated range management and research will result in an improvement in range resource management, especially in the fields of range condition assessment and monitoring, evaluation of the long-term success and acceptability of management practices, biomass productivity and range preservation. Management practices must be evaluated firstly according to their ability to preserve and/or to improve range habitat condition. Habitat attributes must be used as the primary indice of range condition and trends. Management strategies must be adjusted or devised to specifically preserve and improve the range habitat. Once habitat preservation is ensured, management and research can go all-out to optimise productivity. However, the continuous monitoring of habitat condition trends is of cardinal importance to ensure a timely warning of changes in range condition. In this way range preservation can be ensured at all times by adjusting management strategies before substantial habitat damage has occurred.

Research is necessary to answer important questions such as:

- How does, amongst others, stocking rate, animal type, period of occupation, season of grazing, fire, physical farm planning, climate and bush control effect habitat condition?

- How does habitat condition effect phytomass and biomass productivity? (Quantification of production losses due to habitat changes would serve as an incentive for more habitat orientated range management.)

- Are present grazing practices adequate to preserve the habitat? To what extent must they be adjusted to achieve habitat preservation and\or improvement?

- Which vegetation types, land forms and soil types are especially prone to habitat retrogression?

- To what extent do range improvement strategies, e.g. covering of denuded areas with cut plant material from less degraded areas, reseeding, physical breaking up of soil crusts and chemical treatments, improve habitat condition?

- How does habitat condition effect species composition, diet selection, phenology of important grazing species and defoliation thresholds of important grazing species?

- How important is habitat condition in high rainfall areas? (Aspects like enhanced run-off and subsequent erosion may be of special significance in such areas. Similarly the role of reduced rainfall effectivity in the worldwide desertification process, especially in semi-arid and arid rangelands, must not be underestimated.)

These research questions need to be addressed to ensure optimal range productivity and resource conservation in the long-term.

A new environmental management philosophy

A rainfall effectivity orientated environmental management philosophy is regarded as the key to successful management and preservation of natural resources. Generally speaking, the basic natural resources which sustain terrestrial life are soil, water, oxygen and solar energy. The ultimate challenge of mankind is to strive for optimal utilisation and preservation of these basic resources, thereby ensuring the long-term survival of biological life on earth. It is, however, not possible to increase the amount of radiation, soil, oxygen or rainfall substantially without great cost. We are therefore pressed to make the most of the natural resources as they are. The challenge of optimal utilisation of available resources, concomitant with resource conservation, can be met through rainfall effectivity orientated environmental management and monitoring. Rainfall effectivity is the most important environmental aspect where mankind can, and must, make a positive contribution for the benefit of the world and all its inhabitants. Rainfall effectivity can be defined as the fraction of the total precipitation which infiltrates the soil profile and is subsequently retained for utilisation by terrestrial organisms. Numerous factors influence the effectivity of rainfall. These include: Anthropologic activities; vegetation structure, type and cover; actions of terrestrial animals; topographical characteristics; type of rainfall; soil infiltrability, compaction and crusting; run-off and erosion (Stallings, 1957).

Optimal rainfall effectivity ensures, amongst others, minimal run-off from catchment areas, unpolluted draining systems (e.g. no silting and nitrification of freshwater resources), sufficient ground-water and freshwater reserves, soil conservation and optimal biomass production. In contrast, substantial reduction of rainfall effectivity results in enhanced run-off and sediment loss (flooding, erosion), decrease in ground-water and freshwater reserves, environmental instability and increased aridity (Snyman et al., 1984; Snyman et al., 1985; Roux & Opperman, 1986) Generally, environmental retrogression can be ascribed to substantial reductions in rainfall effectivity due to many decades of mismanagement. The worldwide desertification phenomenon, for example, can principally be related to a continuing decrease in rainfall effectivity. The most devastating effect of an unchecked decrease in rainfall effectivity is an universal decline in biomass production. Soil moisture deficiencies caused by reduced rainfall effectivity have a detrimental effect on levels of photosynthesis (subsequently giving rise to a decrease in the production of oxygen). Available solar energy is thus not used effectively by plants, resulting in a substantial reduction in biomass production (Snyman et al., 1980). Managing for optimal rainfall effectivity should be fundamental in land management if these and other related problems are to be addressed successfully.

Rainfall effectivity is influenced by many important environmental attributes (e.g. vegetation and soil attributes, animal activities). Consequently, rainfall effectivity is regarded as a useful indice of environmental condition, stability and trend. Any significant changes in rainfall effectivity will indicate changes in the environment. Ideally, environmental changes (natural or man-induced changes) should either improve or not affect rainfall effectivity. Any environmental change which does not affect the long-term rainfall effectivity substantially, will coincide with environmental stability. One way of monitoring and assessing rainfall effectivity is to compare the rainfall effectivity (displayed in upper layer soil wetness) of reference and test areas subjected to similar environmental conditions and inputs. The environmental "state of health" of a test unit could therefore be established and the trends in environmental condition and rainfall effectivity monitored. In this way the impact of any anthropological activity on the environment could be assessed. Furthermore, the environmental acceptability of cultivation practices and range management strategies could be determined. Assessments can be done by simply comparing the rainfall effectivity of maintained reference sites (representing optimal rainfall effectivity) with those of test areas. Similarly, the success of strategies aimed at improving rainfall effectivity can be evaluated.

A global environmental policy aimed at maintaining, increasing and optimising rainfall effectivity is essential in order to ensure the preservation of basic natural resources and to enable sufficient and sustained food production for the worlds masses. Such policies must be formulated soon and enforced strictly if the survival of mankind and his environment are to be ensured in the long-term.

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