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Rangeland Management in the Southern Karoo (South Africa):

Conflicts of Landuse and Environmental Conservation

(Report of a Scientific Students´Excursion)

edited by:

Josef Settele[1], Irene Hoffmann[2], Reinhold Jahn[3], Jörg Samietz[4], Christine Schäfer[2], and Doris Vetterlein[3]

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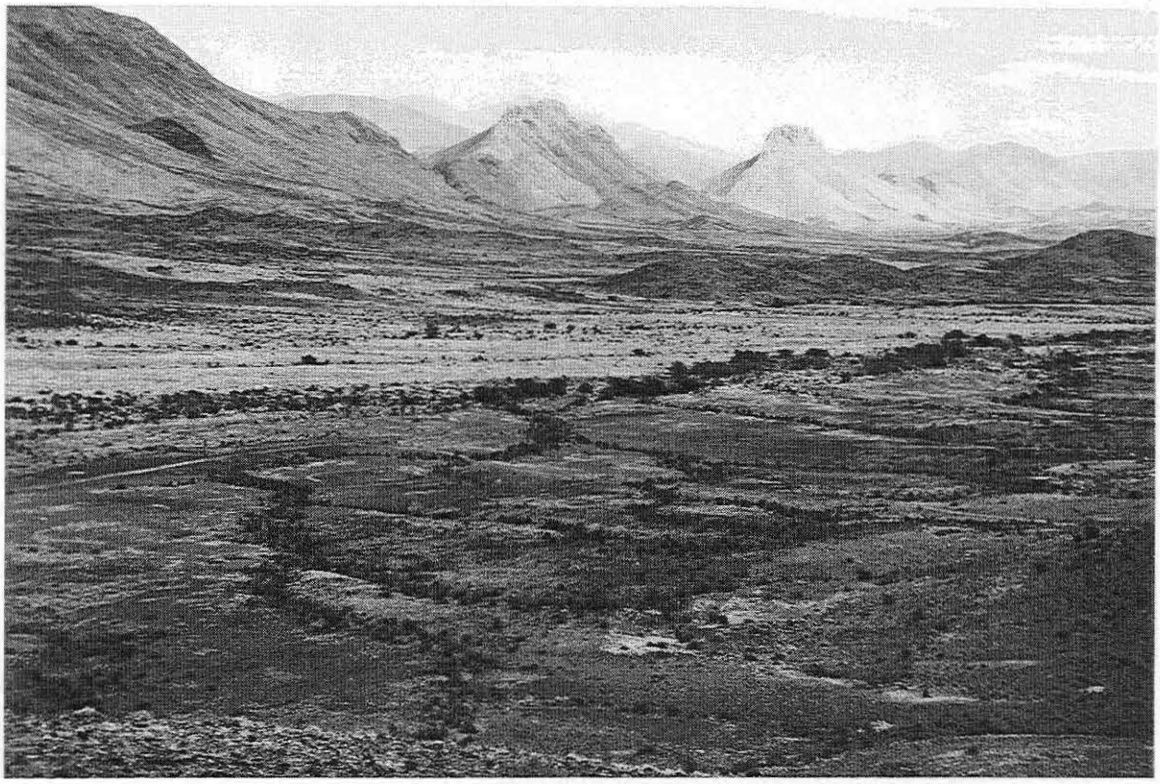

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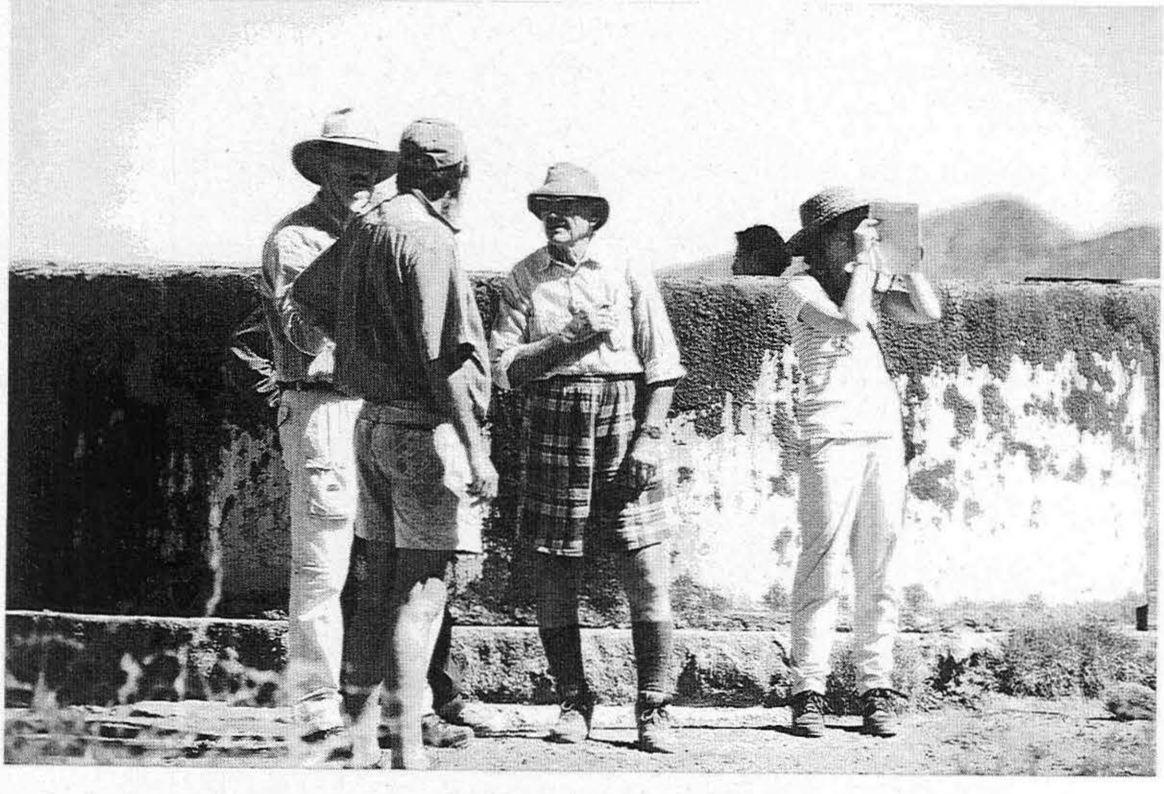

Picture 3: Expert discussions at the very beginning of the investigations in the Prince Albert area (March 1998)

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and participants of scientific excursion to Prince Albert/South Africa
(in March/April 1998)

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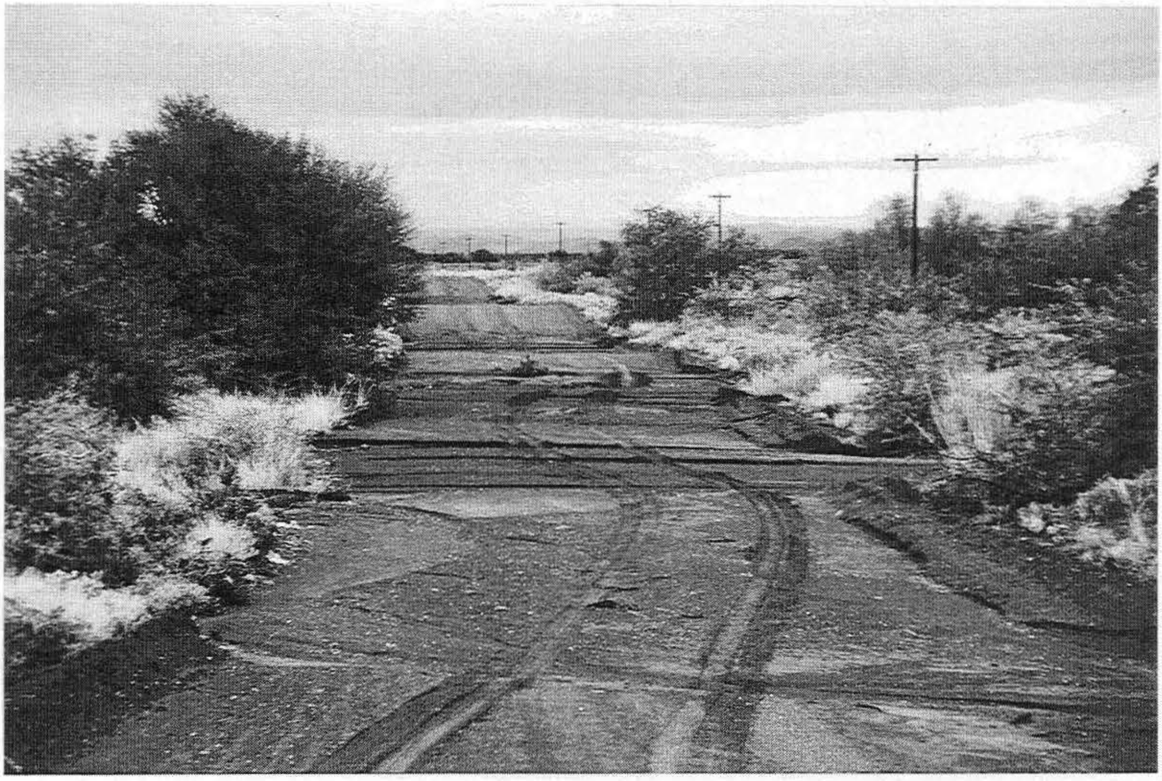
MLU: Martin-Luther-University Halle;
FSU: Friedrich-Schiller-University Jena;

Picture 4: Thunderstorms with heavy downpour approaching the research area near Prince Albert (March 1998)



Picture 5: After the heavy downpour the slippery roads could hardly be used, which caused some changes in the research programme (March 1998)

Chapter 1

Abiotic, biotic, and social aspects of grazing systems in the Southern Karoo (South-Africa) - objectives and frame conditions of a scientific students' excursion

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1.1 Introduction

Grazing of domestic livestock is shaping landscapes in many regions of the world. Selective grazing and high stocking rates of domestic animals had strong effects in arid regions in the past (OLFF & RICHIE 1998). Grazing management in the semi-arid South African Karoo had altered vegetation textures within a few decades (MILTON et al. 1992). The grazing caused decline of vegetation ground cover, and relative abundance of plants was shifted due to their palatability, also plant morphology changed under predation towards a higher proportion of wooden structures (MILTON et al. 1992).

As a representative example of such developments we selected the area around Prince Albert (north of the Swaartberge; South-Africa) for the investigations within our scientific students' excursion and had a particular look at piospheres around artificial waterholes, i.e., we studied the gradient of land use intensity from the waterhole (temporal high density of lifestock, trampling effects) to sites of increasing distance from the hole and thus supposedly less impact of lifestock.

Some of the basic ideas for research during the excursion have been derived from modelling papers by JELTSCH et al. (1996), who were working on piospheres in Northern South Africa, and by WIEGAND et al. (1995), who studied the vegetation dynamics of an ungrazed shrub ecosystem near Prince Albert (i.e. the same area on which part of our study was conducted: the 'Tierberg' site).

1.2 Research area: Prince Albert (Southern Karoo, South-Africa)

1.2.1 Geographical setting, abiotic and biotic frame conditions

Prince Albert is situated on the southern edge of the Great Karoo, 20 km north of the Swartberg mountain range (Fig. 1.1, taken from MILTON et al., 1992).

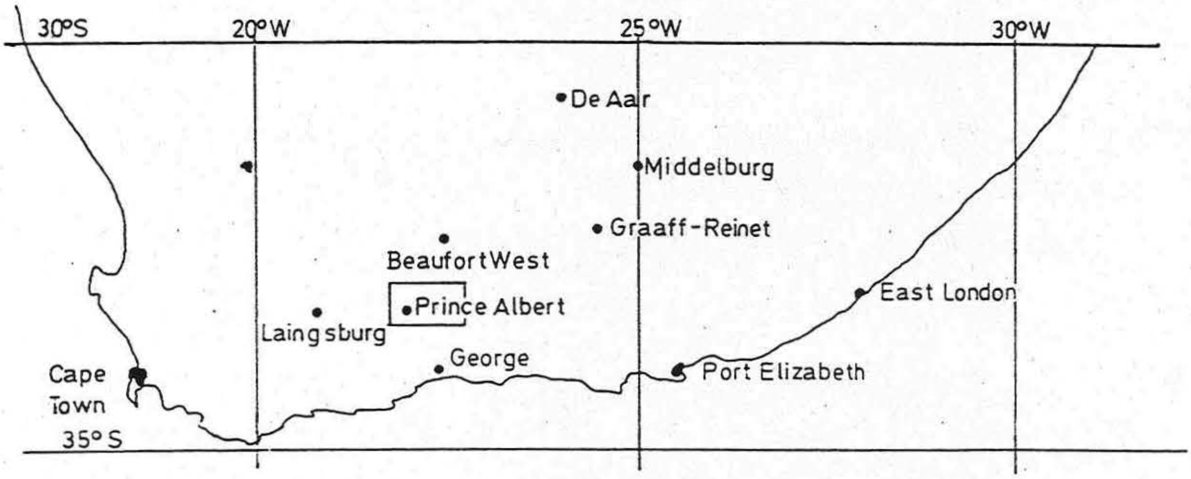


Figure 1.1: Geographical setting of Prince Albert, the research area of our excursion (from MILTON et al. 1992)

The mean annual temperatures of the study areas is 17.5°C, however, extreme daily variations occur, reaching from below 0°C up to more than 30°C.The average annual rainfall is 167 mm. The period from September to January is mostly dry, highest precipitation occurs between February and May. Winter rain falls are frequent but rarely strong. During summer thunderstorms, sometimes with hail, are rather common. These normally result in rapid runoffs and flash floods. Wind directions in the study area are south-east during summer and north-west in wintertimes (MILTON et al., 1992).

[comment: geology and soils of the area are not included in this introductory chapter, as they have been a major research object during the excursion and are dealt with in detail in chapters 3 to 5]

Based on climatic factors (46 % of precipitation during the winter months and a summer aridity index of 4.8), the study area falls into the interface between Succulent Karoo, Nama-Karoo and a succulent form of the Savanna Biome (RUTHERFORD & WESTFALL 1986).

The vegetation on the study region closely resembles the Little Karoo form of Karroid Broken veld on account of its high proportion of succulent species and low abundance of grasses (ACOCKS 1975). Geographically it falls within the Koup Karoo (HILTON-TAYLOR 1987).

1.2.2 Study sites of natural science working groups

The criteria for the selection of the research sites are a direct consequence of our objectives. Therefore we have been looking for sites which should differ in nothing but the grazing regime. Ideally we would have liked to conduct research on two grazing gradients (piospheres) and one area with no grazing.

Major problems however have been, that (understandably) not all farmers are really keen on having dozens of students on their land and that the areas of the many farmers who did not oppose to our endeavours always differed in several aspects. A major problem has been, that the grazing history of many rangelands is not well known and especially at present quite some of them seem to have been at least temporarily abandoned.

After all we selected two piospheres with a bit different history and one reference site. In the course of the activities it turned out to be impossible to really cover two grazing gradients within the set time frame, thus we decided to study only one and the reference site, in order to be able to do a more in-depth analysis and to experience (and teach) a broader spectrum of methodologies (always bearing in mind, that the same type of analysis should have been done on at least one or better some further piospheres to really achieve scientifically sound results).

Two study sites have been analysed: "Sandrivier" and "Tierberg". Both are situated on the southern edge of the Great Karoo (33 ° 10' S, 22 ° 17' E), 20 km north of the Swartberg mountain range. "Sandrivier" study area is located on a plain between some little hill ranges, about 18 km east of Prince Albert. "Tierberg" (actually the Tierberg Karoo Research Centre with an area of approximately 100 ha; see MILTON et al., 1992) lies about 26 km east of Prince Albert at 800 m above sea level in the 5 km wide and 80 km long valley of the Sandrivier, which flows east along a syncline in folded Ecca shale beds for approximately 60 km before joining the Gamka river. Tierberg was selected as a reference site for its flatness and homogeneity of vegetation in comparison to the grazed area Sandrivier. Tierberg is drained by six small washes, which join a single drainage line running SSW, but the surface water is present in the area only during heavy rainstorms, when run-off is rapid and muddy rivers incise the washes and drainage line. The research centre itself is an exclosure out of grazing since 1987 and lies on the Tierberg farmland that itself has a history of moderate grazing (see MILTON et al., 1992, for further details).

A general map of the study areas Sandrivier and Tierberg and the position of the examination sites A to E in Sandrivier is given in Figure 1.2.

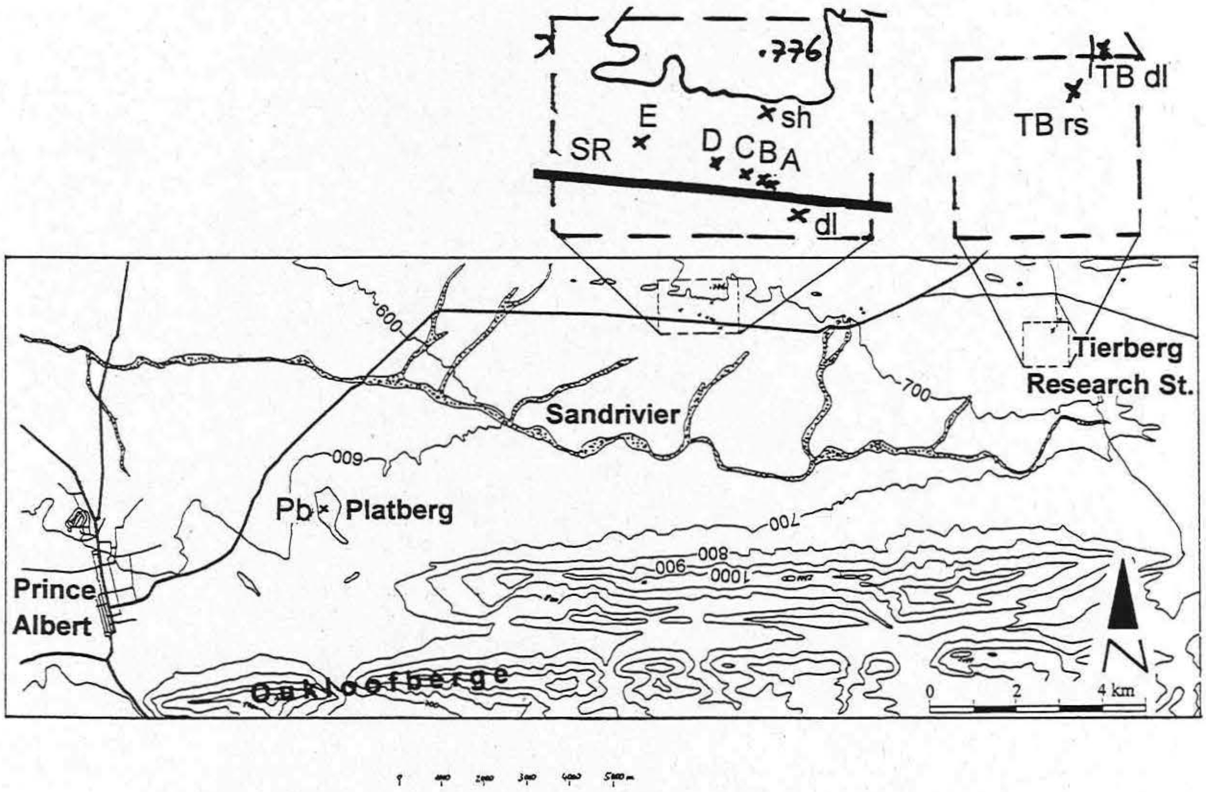


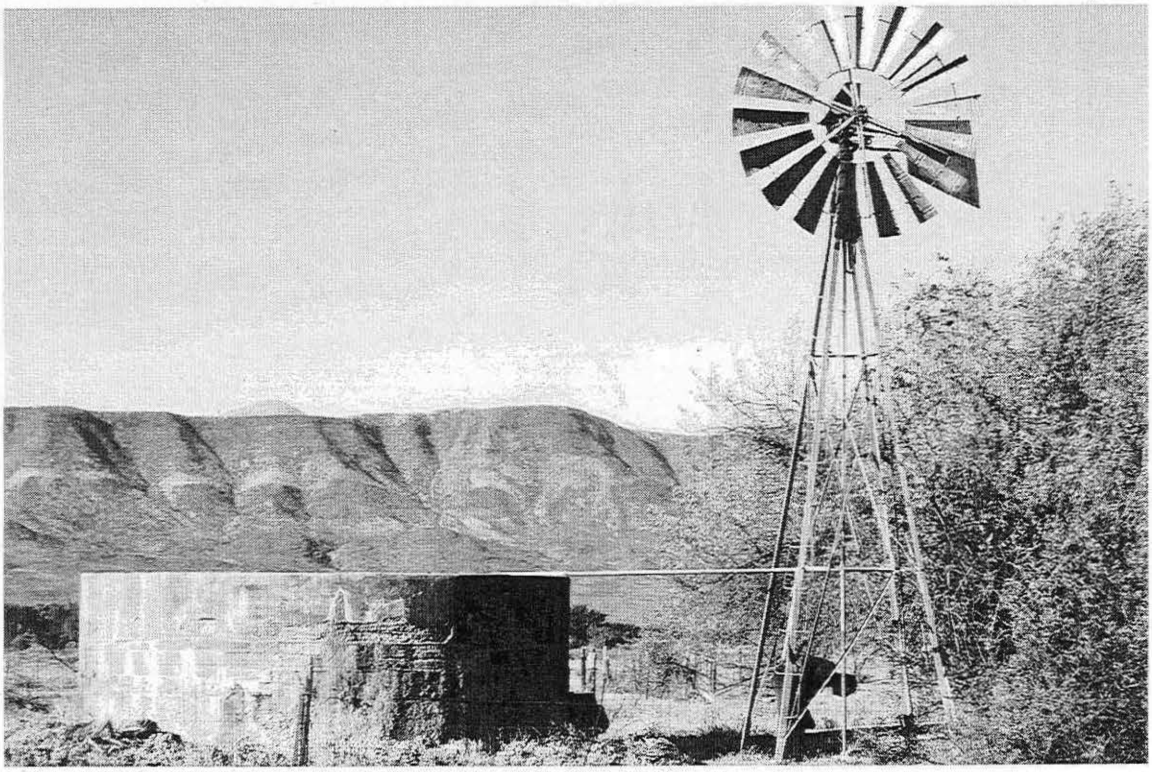
Figure 1.2: Overview of the study areas Sandrivier and Tierberg and the position of the examination sites A to E in Sandrivier

Picture 6: The piosphere of Sandrivier (March 1998)

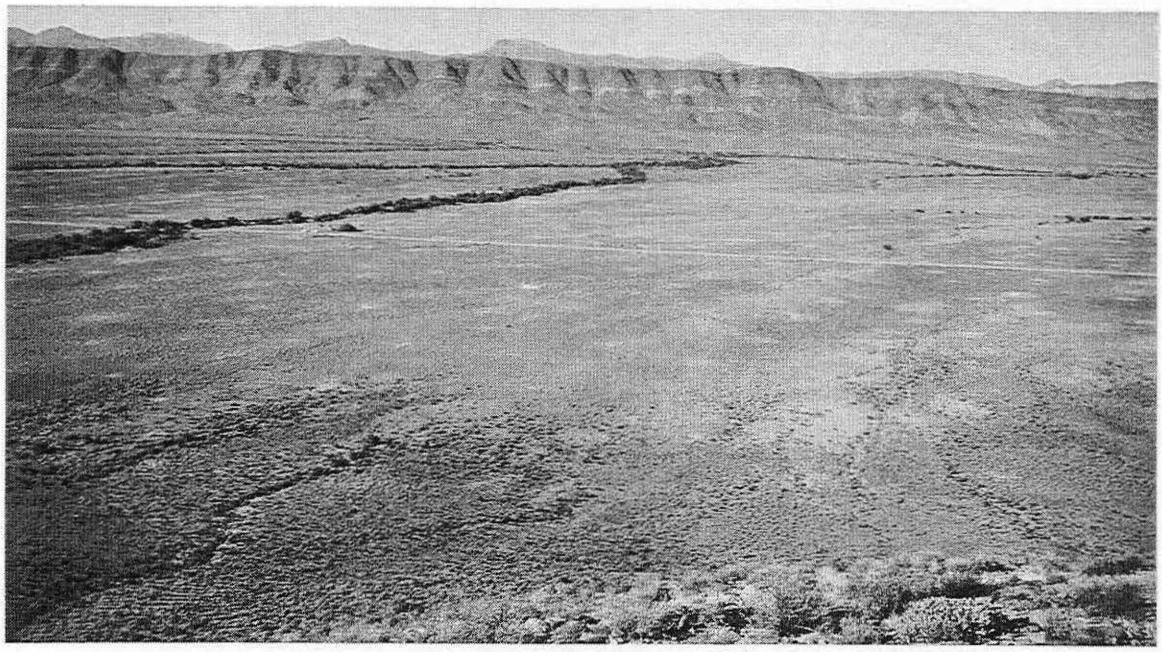
In the research area two different habitat types can be distinguished: the plains with small, perennial shrubs and bare ground between them as the water runoff sites, and the drainage lines with higher shrubs and trees as the water run-on sites. Habitat types differ in vegetation height and structure and species composition (MILTON et al. 1992). Drainage lines serve important ecological functions, they offer food and nesting material for birds, hides and shelter for wild and domestic mammals, and shadow during daytime. Washes, somehow intermediate between plains and drainage lines in plant species composition, were treated together with drainage lines in this study.

On the study sites four types of habitat have been distinguished: plains, heuweltjies, washes and major drainage lines with different species and plant cover (compare chapter 7). The differences of vegetation in runoff lines (plains with small, perennial shrubs and bare ground between them; and heuweltjies - nutrient rich patches about 13m in diameter, probably of zoogenic origin - compare e.g. LOVEGROVE & SIEGFRIED 1989, MILTON & DEAN 1990, and also chapter 6) and runon lines (drainage lines with higher shrubs and trees; and washes, which are somehow intermediate between plains and drainage lines in plant species composition) can at least partly be explained by their soil moisture status. In addition, soil chemistry – nutrient status of heuweltjies is 3-5 times higher than the surrounding plains (compare chapter 6 by KAHLE et al.) – and, of course, grazing of domestic livestock influence the vegetation features (compare chapter 7 by BAUER et al.).

The general plant community is characterised by evergreen and deciduous succulents (*Ruschia* spp., *Malephora lutea, Augea capensis, Brownanthus ciliatus* etc.) and by taller non-succulent shrubs such as *Pteronia* spp., *Galenia fruticosa* and *Osteospermum sinuatum*. Underneath the shrubs there are few annual forbs and between the single shrubs interspaces with no vegetation.



Picture 7: Windmill of waterhole of the Sandrivier study area (March 1998)



Picture 8: Overview of valley with Sandrivier study area (March 1998)

1.2.3 Study sites of social science working group

Quite different from the approaches of the natural scientists, social scientists are less confronted with detail work on farmers field. Rather they are confronted with the main actor himself: the farmer. Not surprisingly, the social science group had to conduct many interviews which of course results in a large number of "study sites". One precondition here has been the willingness of the farmers - as well as other actors confronted with the agricultural and administrative sector - to give information about the conditions the are working in and their personal views on aspects like the general development. See chapter 2 by HOFFMANN et al. For a more detailed account of the methodology and all other aspects of the activities of the social science group.

1.3 Participants

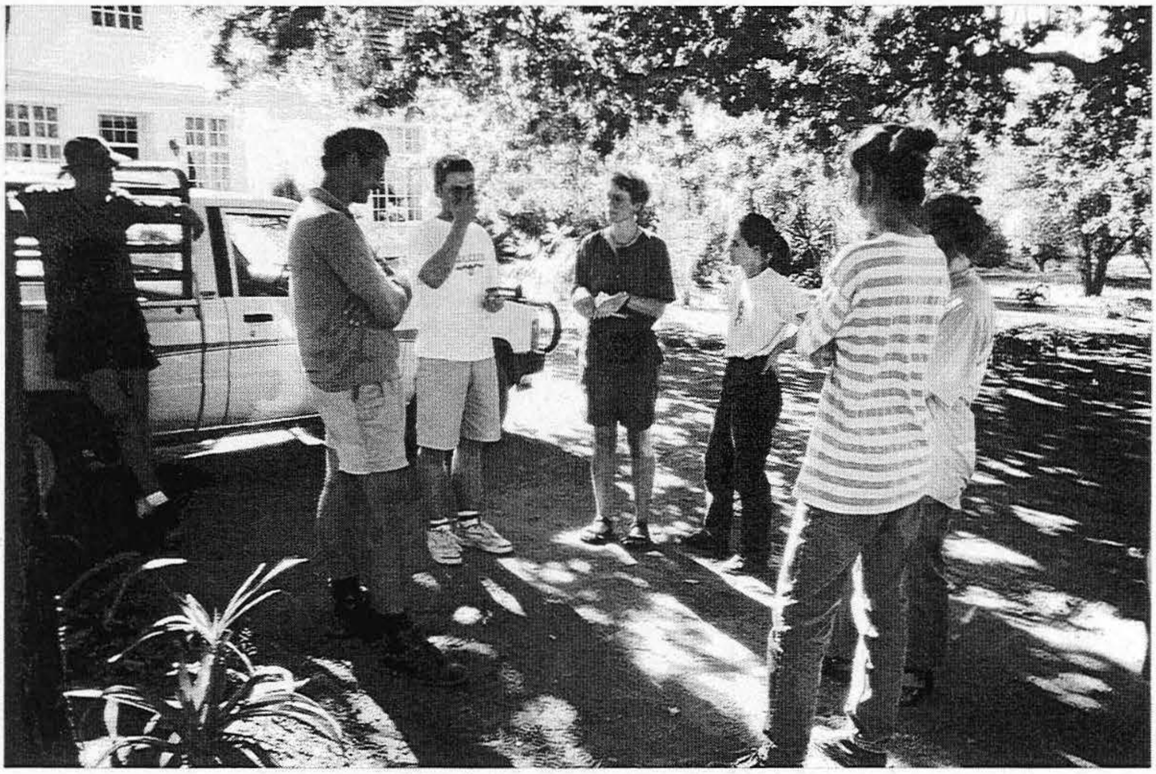
The excursion was organised by university teachers of

- UFZ - Centre for Environmental Research Leipzig-Halle (J. SETTELE, K. & T. WIEGAND),
- Justus-Liebig-University Giessen (J. HOFFMANN, C. SCHÄFER),
- Martin-Luther University Halle (R. JAHN)
- Brandenburg-Technical-University Cottbus (D. VETTERLEIN; now Martin-Luther University Halle), and
- University of Jena (J. SAMIETZ).

The students (compare list of contributors and participants on page 5) represented the following university courses:

- agriculture (with specialists in plant production, agro-ecology, environmental safety, human nutrition and sociology),
- biology (emphasis: nature conservation, botany, zoology), and
- environmental engineering (esp. soil conservation).

Picture 9: Introduction to Karoo ecology by Sue MILTON (March 1998)



Picture 10: Interviews with farmers of Prince Albert area (March 1998)

1.4 Objectives of the investigations

The experience of interdisciplinary and scientifically as well as socially relevant research was the major objective of the two-week field study. This had to be achieved by confronting students and supervisors with the problems of people living in a system with rapid and fundamental changes. Based on long-term experience in the region of Sue MILTON and Richard DEAN, it was possible to investigate a broad variety of aspects of this landuse system. The task also has been to put results of such detailed work back into the landscape ecological frame later on, and to prepare a public presentation of the results, which was given in Prince Albert (our main investigation area) as well as at the University of Capetown (UCT) at the end of our stay. Additionally, a temporal cooperation of our group with an international students' group from UCT, doing a field course on disturbance ecology in and around Prince Albert and supervised by Sue MILTON and Richard DEAN, added additional flavour to the whole interdisciplinary and intercultural undertaking!

1.5 Working groups

Field work was conducted in several working groups:

Socioeconomy: As new developments are only possible with the people implementing them, work of this group was of overall relevance for all other groups. The main task was to get some ideas about the frame conditions and the farmers' own view of their future. Reliable information on some of these aspects is essential for future activities and scenarios of development. The detailed results of the group are summarised by HOFFMANN et al. in chapter 2 of this volume.

Geology and Soils: Main task of this group was the characterisation of the different soil types and their impact on land use potential. The results are summarised in three contributions. First an overview on the regions geology by JAHN (chapter 3), then the soil data itself by RÖßNER et al. (chapter 4) and finally a specific analysis of the root distribution on some of our research sites by DRATH (chapter 5).

Nutrients: Members of this group made in depth analyses of the nutrient conditions in areas of different grazing intensity. The results are summarised in KAHLE et al. (chapter 6).

Botany & point pattern: Analysis of changes in species composition and abundance in relation to landuse intensity was the main task of the botany group. Their results are summarised in BAUER et al. (chapter 7) and in BOßDORF & SCHURR (chapter 8).

Zoological groups: Three smaller groups worked on specific aspects of the zoology: the first one on the fractal dimensions of vegetation and their relevance for arthropod communities (see chapter 9 by HELD et al.), the second one on small mammals in grazed and ungrazed areas (chapter 10 by ECCARD & WALTER), and finally a brief inventory on butterflies mainly around Tierberg was made (chapter 11).

1.6 Presentation of activities and results

Smaller presentations have been done on several evenings in March 1998 in Prince Albert, while the main presentation took place in early April 1998 at UCT (University of Capetown), for which practically all participants have shown the findings of the two weeks' research.

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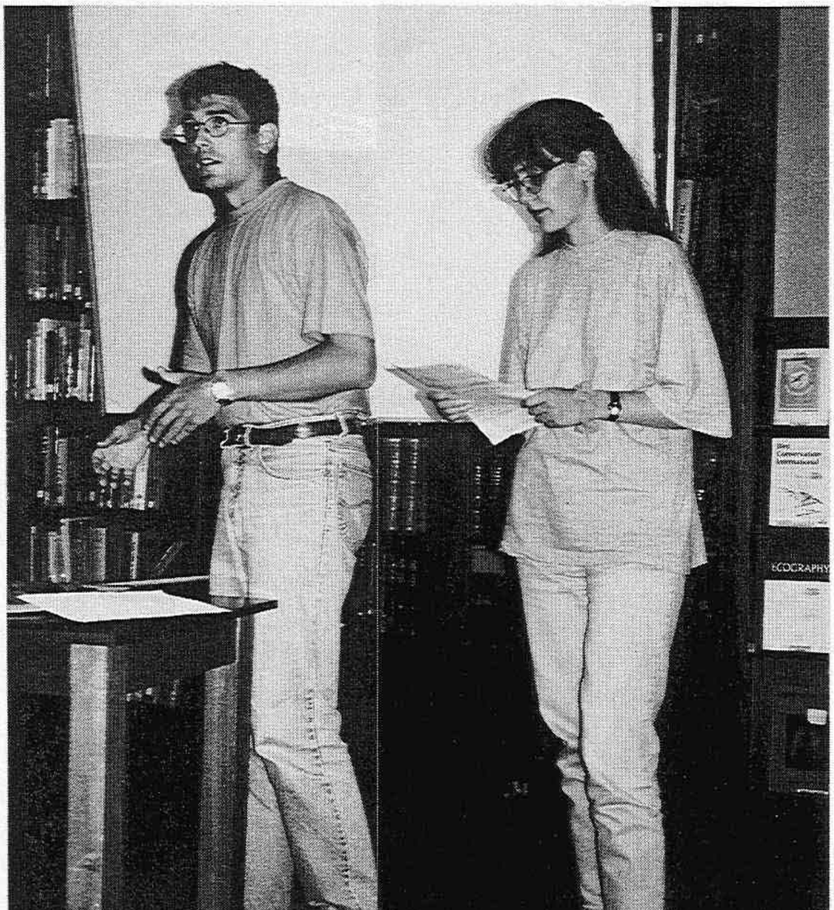
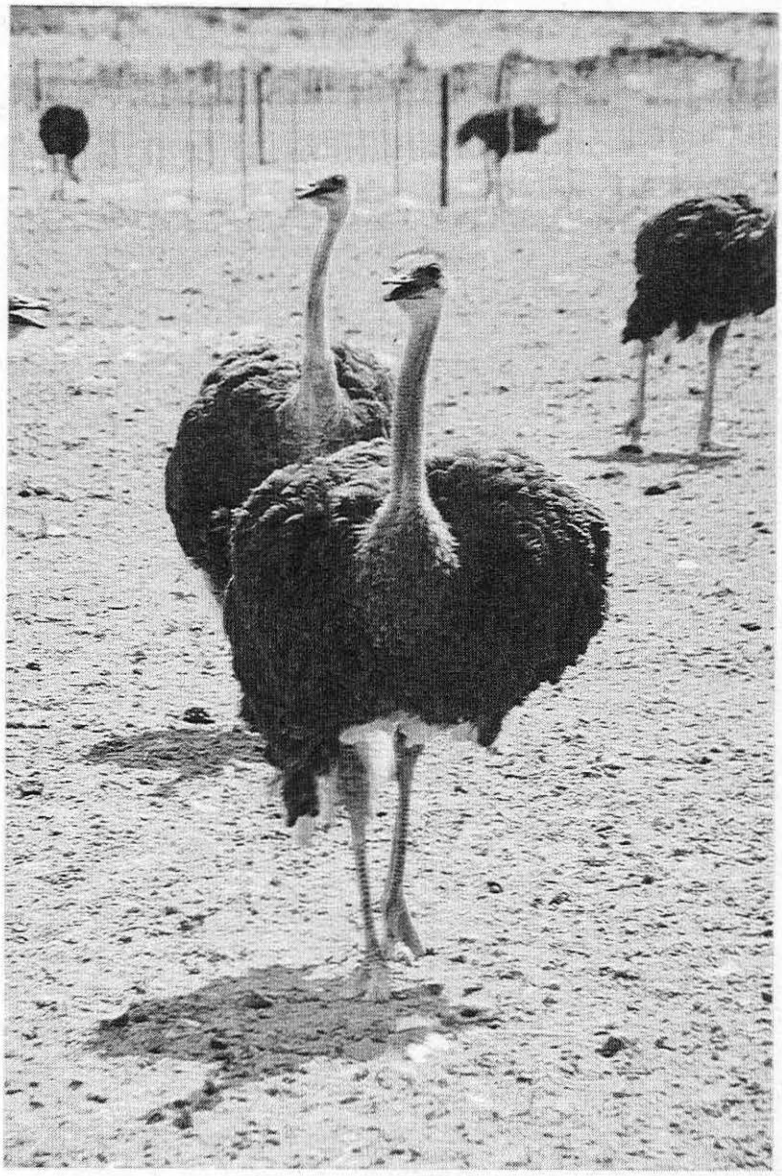


Picture 11: Presentations at UCT (University of Capetown) in early April 1998



Picture 12: Typical representative of domestic livestock in the Southern Karoo

Chapter 2

Livestock production systems in the Karoo

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2.1 Introduction

Most of the ecological studies undertaken during the excursion took place at Tierberg or Sandrivier farms. However, looking at livestock-influenced ecosystems presupposes knowledge about the livestock system, especially in a semi-desert ecosystem, where dominant plant species live up to several decades. This includes most of the palatable plants which are grazed by sheep on the veld around Prince Albert. Considering the long life spans of the plants and the long recovering periods of degraded vegetation, the history of the farms and their development becomes very important. Agricultural production methods and changes during the past seem to be responsible for much of the damages in vegetation. They are still visible today, i.e. a lot of degradation of the veld seems to be inherited and not created by the actual farmer.

Therefore, our (the socio-economics) group intended to describe the existing livestock production systems and their historical development. Objectives of the study were the

- description of the historical development of the agricultural production system in the Karoo
- description of the most important livestock production systems in the area
- assessment of general ecological consequences of livestock production systems

2.2 Methodology

Informal interviews were conducted with 11 farmers, of which 9 belonged to Prince Albert (PA) District and the remaining 2 lived in the adjacent District of Klaarstroom. The farmers interviewed in PA represented 12% of the inhabited farms. The farmers were asked about the history of the farm and the boreholes, water quality of boreholes, number of camps and their management and the farm enterprises other than livestock. All farmers were very co-operative and took their time to show the interviewers around. Transect walks were done in order to identify the state of the veld, to see the animals, and to obtain further information. The interviews lasted between 2 and 8 hours. Interviews were also conducted with several administrative offices and businesses in Prince Albert to get additional information about population number and structure, and economy. In the following text, information gained in interviews was combined with literature studies in order to give a comprehensive idea about the livestock production systems in this part of the Karoo.

2.3 Agricultural production in the Karoo

2.3.1 Early developments

The total area of the Karoo is 29,062,000 ha (Dept. van Landbou 1986), covered mainly by shrubland. Development of land use in the Karoo before the 19th century was characterised by open rangelands for herds of springbok hunted by the San. Pastoral use by transhumant Khoikhoi existed during the rainy season when surface water supply was sufficient for livestock. During the 18th century, the game and the San were decimated by firearms. Transhumant trek-boers took the land from the pastoral Khoikhoi and settled around permanent springs (SMITH 1992, ILLIFE 1997).

2.3.2 Before World War II

Following the discovery of diamonds and gold ores in South Africa, but also in the Karoo, at the end of the 19th century the "mineral revolution" started. Industrialisation, urbanisation and an increasing number of immigrants created a growing demand for food. Local and national markets developed requiring new agricultural production lines, eg. fruit and wool production in the Prince Albert area. Prince Albert became famous for its apricots. The Land Act of 1913 (expropriation of many black land owners in favor of white farmers) promoted the commercialisation of agriculture in South Africa while on the other hand, forming an unskilled black or coloured labour force, especially needed for the mining industries. This economic boom ended with the global economic crisis in 1929 and an era of protective trade policy. In the Karoo, these developments did not have the same strong impact on agriculture as in other parts of South Africa because of the difficult local natural conditions. Especially the shortage of water limited farming to a few products like wool, mutton and irrigated apricots for a very long time.

Up to the 1920s, about ten white and coloured families lived on a typical Karoo farm. Farming was for subsistence only, which included vegetable and cereal production. Different kinds of animals were kept on the farm: donkeys, cattle, sheep, goats and horses. Some were used for food supply, some particularly for draught purposes. Livestock number was high, because horses were used by shepherds, and most of the coloured men had a donkey cart for transport. Being self-sufficient in milk required four cattle other than the dairy cow. During that period no fences existed, the only water available was provided by natural waterholes. Unlike the actual pasture management system, the animals were herded by shepherds during daytime and were kept in kraals during the night to prevent losses caused by predators. The degraded vegetation around farm houses, natural waterholes and old kraaling areas still shows the high grazing and trampling impact dating from that period.

From 1920 to 1930 the technique of borehole drilling was developed. It formed the technical basis for fence building. Most of the boundary fences date from this period, when wire became readily available. Fencing was motivated initially by predator control (shakal save fences). The boreholes improved water supply for lifestock breeding and induced a change in agricultural production from subsistence farming to market-oriented wool production. Angora goats and Merino sheep were introduced.

Transhumance was practiced up to the 1940s. Farmers with only small farms in the Karoo trekked towards the northern grassland regions during summer. Trek-routes were well defined, and agreements existed with bordering farmers to use their camps. The herds walked about 3 to 4 km a day on trek-routes 400 m wide. The traces of these intensively grazed and trampled routes are still visible in the landscape. Stocking rates were high at about 3 ha per sheep.

2.3.3 After World War II

The unsatisfied demand for consumer goods on the domestic market coupled with a prosperous phase in world economies led to a boom phase in South Africa. The low population density and and the low purchasing power of the domestic market, due to the black population majority, forced commercial farmers to enter the world market. At the end of the 1960s, flexible exchange rates were introduced, resulting in a continuous increase in price indices since 1971 (Fig. 2.1). Export oriented farming expanded, depending on the fluctuating world market prices for agricultural products. Subsidies as a buffer were never introduced on a large scale. However, the South African Government was farmer-friendly. For example in the early 1990s, all state-run abattoirs had to pay 2% of the slaughter revenue to the state, which used the money to support agricultural research and extension or for drought support.

In 1985, the EU and USA implemented sanctions and consumer boycotts against the Apartheid system in South Africa, which had a devastating effect on the country. Consequently, the farmers had only very limited access to the European and US-market. In Prince Albert District the farmers profited from the natural conditions that are very well suited for ostrich breeding. From 1805 to 1994 there was a constitutional law giving the Klein Karoo Kooperative (KKK) in Oudtshoorn the national monopoly for ostrich purchase, slaughter, processing and sale. In Prince Albert, the ostrich industry established in 1988 after the Oudtshoorn monoploy weakened. Farmers started as contractors for farmers from Oudtshoorn and then built up their independent ostrich enterprise and became member of the KKK. The ostrich boom in Prince Albert lasted from 1988 to 1993. During that period, even backyard farmers in Prince Albert town cut down their apricot trees, planted lucerne and started raising ostriches. An economic stratification developed. While some farmers specialised in ostrich breeding up to 3 months old animals, others specialised in fattening from 3 to 14 months of age, and larger farmers did the whole production line with breeding birds to hatching, raising and fattening. Since export of breeding ostriches was forbidden, the Karoo region and South Africa held the global monopoly of ostrich production. Nevertheless, for reasons of political isolation, most sectors of the South African economy focused more on the domestic market than on the world market.

The wool price in South Africa was controlled from about 1950 to 1995 by the Wool Board. This organisation buffered the wool price fluctuations, enabling farm income to be smoothed (higher than the lowest world market prices, lower than the highest prices). In this way the South African producer price was not closely connected to the world market price, which is driven by world demand for natural fibre. However, the national wool price depends on the world wool market, resulting in high fluctuations especially after the mid 1980s (Fig. 2.2). An over supply of fine wool on the world market led to a fall in wool prices, that was only passed on to South African farmers in the early 1990's. South Africa now competes on the world wool market with Australia. The number of wool sheep declined in 1971 and slightly in the mid 1980s. Between 1991 and 1997, sheep numbers in South Africa declined by 1.8% p.a.. Goat numbers increased by 1.65% p.a. during the same period (FAO 1998; compare Fig. 2.3). The decline in sheep numbers probably resulted in a lower wool supply and higher wool prices. Very little wool is used locally, most is exported and processed elsewhere and then re-imported as garments. Coarse wool is imported to South Africa for carpet making.

In the Karoo, the changing importance of meat and wool indicated in Figures 2.2, 2.3, and 2.4 was reflected in a decline of the number of Merino sheep and an increase in the number of other sheep. The number of Dorper sheep exceeded that of all kinds of wool sheep in 1984 (Tab. 2.1).

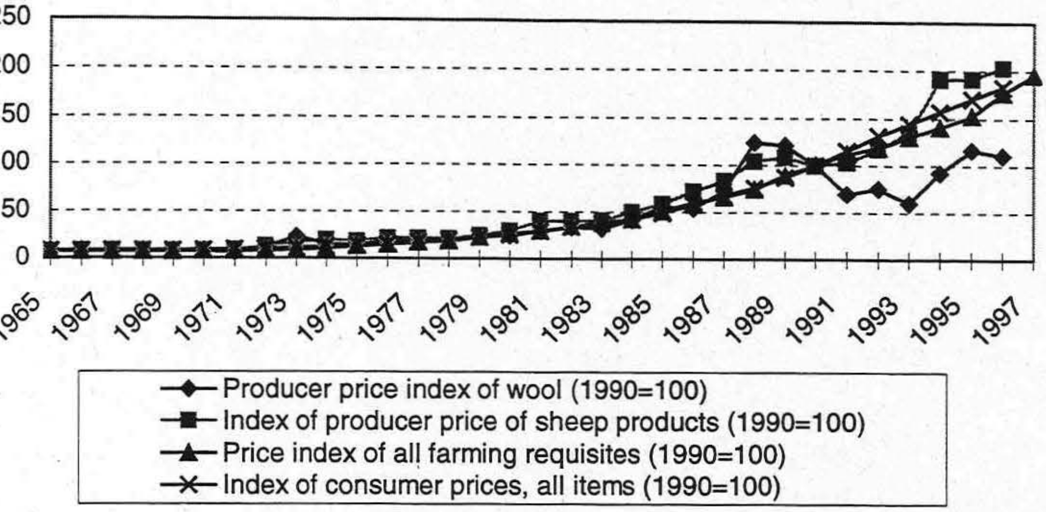


Figure 2.1: Price indices 1965 to 1996
(Source: Republic of South Africa: Abstract of Agricultural Statistics 1998)

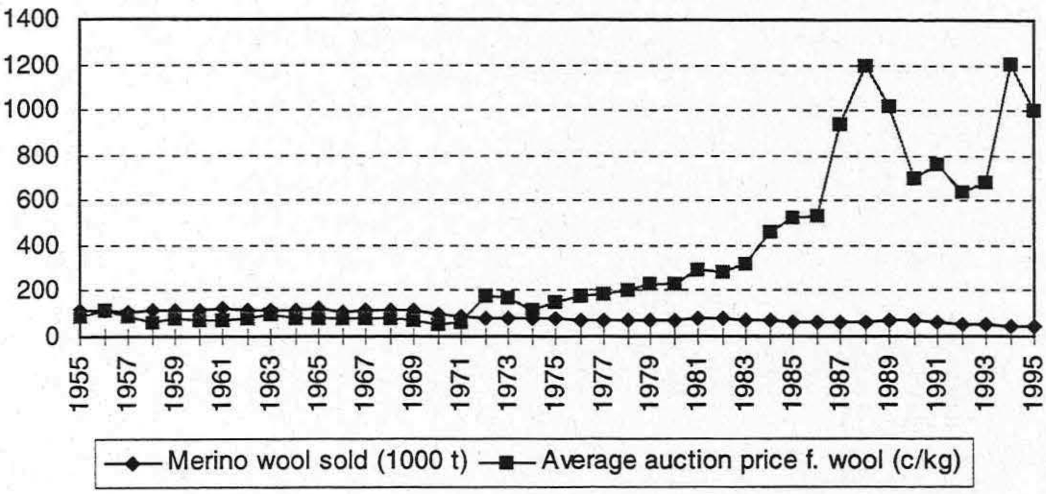


Figure 2.2: Merino wool sales and auction price per kg in South Africa, 1955 to 1996
(Source: Republic of South Africa: Abstract of Agricultural Statistics 1998)

Table 2.1: Livestock number and production in the Karoo
(Source: Dept. van Landbou en Water vorsienning 1986)

	1980/81	1983/84	Percentage change
Merino sheep (n)	63,168	56,539	- 10.4
Other wool sheep (n)	7,334	11,405	+ 55.5
Angora goats (n)	11,702	31,971	+173.2
Dorpers		79,882	
Cattle		1,114	
Ostrich		187	
Merino wool (kg)	271,624	243,117	- 10.5
Other wool (kg)	31,538	49,042	+ 55.5
Angora hair (kg)	48,563	132,682	+173.2

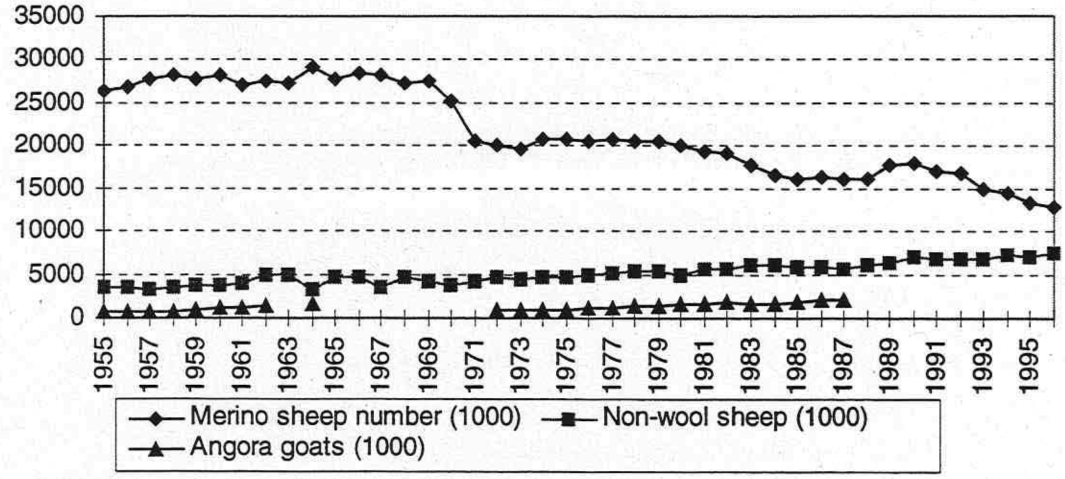


Figure 2.3: Commercial small ruminant stock of South Africa, 1955 to 1996 (Source: Republic of South Africa: Abstract of Agricultural Statistics 1998)

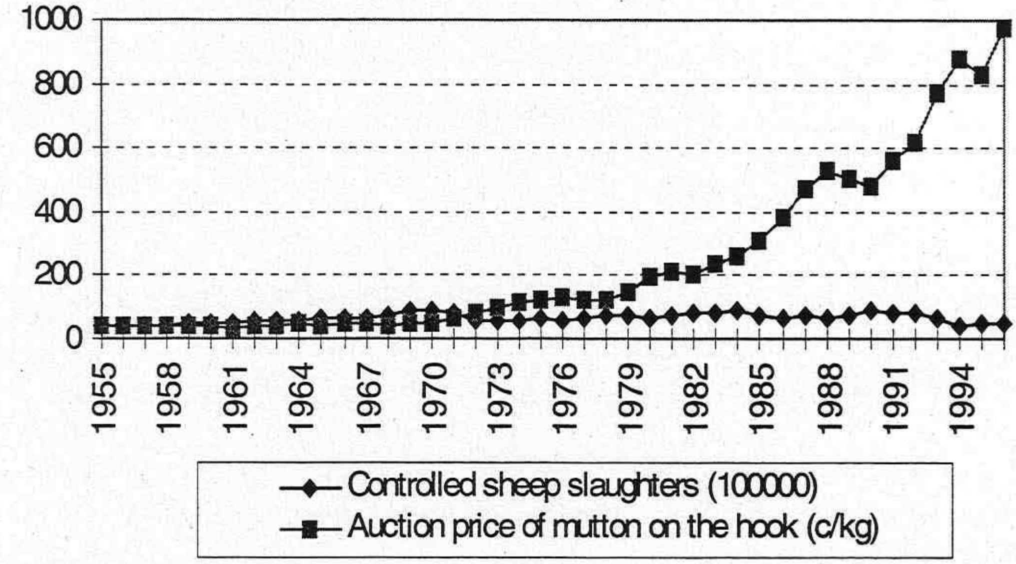


Figure 2.4: Sheep slaughter in slaughterhouses and auction price per kg live weight, 1955 to 1996 (Source: Republic of South Africa: Abstract of Agricultural Statistics 1998)

A dual structure in agriculture is still to be found in South Africa: highly industrialised farms run by white farmers coexist with the subsistence farming of black landowners as a result of the Apartheid system and it's housing policy. In the Nama Karoo most of the land is owned by commercial white farmers, whereas labour force is based on coloured people. Small scale farmers as in former homelands do not exist here (Republic of South Africa 1998). However, in the western succulent Karoo (from Springbok to Richtersveld) communal farms are found. The number of farms in the Cape provinces declined by 48 % between 1950 and 1996. However, the total farm area declined by only 8% (Fig. 2.5). Average land per farm thus increased from 1250 to 2305 ha.

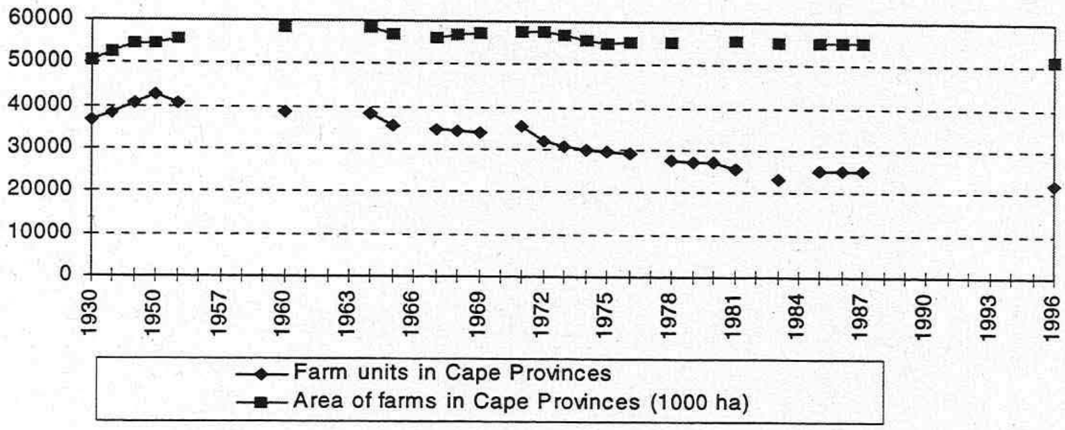


Figure 2.5: Farm number and total area of farms in three Cape provinces (Source: Republic of South Africa: Abstract of Agricultural Statistics 1998)

Livestock production is the most important enterprise for commercial farmers in the Western Cape Province when looking at the land area, followed by mixed farming (Tab. 2.2).

Table 2.2: Commercial farms in Western Cape Province in the mid 1990s (Source: Republic of South Africa: Abstract of Agricultural Statistics 1998)

	Farm numbers	Area (1000 ha)	Average farm size (ha)
Field crops	1,269	1,423	1,122
Horticulture	3,202	1,507	471
Forestry	61	103	1,694
Animal production	2,472	5,177	2,094
Mixed farming	1,691	2,071	1,225
Others	51	30	592
Total commercial farms	8,747	10,312	1,179

The distribution of farm size classes in the mid 1980s shows more small (<3,000 ha) and fewer large (>12,000 ha) farms in Prince Albert than in the Karoo as a whole (Tab. 2.3). The average farm size was about 4,500 ha.

Table 2.3: Farm sizes and farm numbers in the Karoo (Source: Dept. van Landbou en Water vorsienning 1986)

	Farm size class in ha					
	<3,000	3,001-6,000	6,001-9,000	9,001-12,000	>12,000	Total
Total Karoo farmers	3,018	1,880	865	312	338	6,413
Percent of total	47.1	29.3	13.5	4.9	5.3	100
Farmers in Prince Albert	139	71	41	11	7	269
Percent of total	51.7	26.4	15.2	4.1	2.6	100

With special regard to range management, a rapid vegetation degradation due to continuous grazing was observed up to the 1950s. The range management policy of the 1960s included the development of rotational grazing schemes, where land is divided into extensively and intensively used parts. This was based on the assumption that rotating animals around various stock camps at selected times allows heavy grazing. The following resting period allows for better control of the stocking rate. Two to five camp rotations were recommended by the Department of Agriculture and Water supply. Farmers practising rotational grazing got access to subsidies for fencing (SMITH 1992). Most of the internal fences date from the 1960s when subsidies were high. Neither poles nor wires do rot due to the aridity.

During the 1970s, intensive grazing systems, such as non-selective and short-duration grazing, were developed which intended to reproduce conditions prevailing before European intervention. This is based on the assumption, that under "natural" conditions episodic formation of large migratory herds occurred which grazed and trampled all plant species in their path, and that a wide spectrum of ungulates defoliated plant resources equally, producing non-selective grazing pressure on all species. Theoretically, all stock are forced to eat all the plant species, including those considered unpalatable. Most famous among these intensive grazing systems was the "Wheel system" developed in the prairies of the US and in Zimbabwian grasslands (SAVORY 1971). It consists of a rotation of livestock around a central locus (water point) in short (< 1 week) grazing periods during the growing season of vegetation, and longer periods (2 weeks) during the dormant season, and 2 months resting phases for the rest of the land (SMITH 1992). The official recommendation for stocking density in this period was around 3 ha/SSU (SSU = Small Stock Unit).

The 1980s rangeland management philosophy was influenced by the non-equilibrium ecosystems approach. The management of natural resources should be event-oriented and not confined to rigid structures or steady stocking rates (WALKER et al. 1986). A high level of management expertise is needed, and it is assumed that traditional African pastoralists have this, while white South African farmers do not. In the early 1980s, 86% of the area was white-owned. Less than 10% of the white farmers used any developed grazing system to manage their farms (DONALDSON 1984, quoted in SMITH 1992). The Government passed the "Conservation of Agricultural Resources Act" in 1983 (Government Gazette No 3707 Vol 227, May 1984, No 9238), stating that veld has to be managed in a conservative way in order to avoid erosion. The grazing capacity of the veld was defined, as well as weeds and invader plants, and farmers were obliged to eradicate weeds. The stocking rate is calculated with large stock or small stock units per ha (see Fig. 2.6).

Veld quality in the Karoo in the mid 80s, was fairly good only on 0.4% of the total area, medium on 47%, mainly poor on 51% and very bad on 1.6%. The bad regions were mainly found north of Prince Albert towards Willowmore (Dept. van Landou 1986), which were the former high altitude summer-grazing regions for transhumance.

2.3.4 The end of Apartheid

After the first free elections in 1994 the economic situation changed again. Europe and the USA gave up their sanctions and the old trade relationships re-established. The ostrich industry around Prince Albert experienced a severe setback. Due to the weakening of the KKK and previous exports of breeding birds, the ostrich industry in the UK, the USA, Israel and Australia was already well established in 1994. This resulted in a drop of prices on the world market. Producer prices in the Karoo dropped to an extremely low level: from 1700 R per ostrich (14 months, 85kg) in 1997 to 600 R in 1998. Since the average production costs may reach 1000 R, farmers are currently loosing money. Some farmers had anticipated these problems and had already started to diversify their production using the high profits they made during the ostrich boom, others started diversifying production only after the end of Apartheid. For about ten years, the former group of farmers had cleared the veld and planted fruit trees under irrigation, mainly apricots, to supply the European market with the earliest out of season fruits. More elaborate irrigation techniques were developed during the last 25 years and the farmers were able to increase the exploitation rate of their water resources. After the end of Apartheid they intensified their efforts on this sector. The production of vegetable seeds for the European and the US-market increased, for which the area provides favourable phytosanitary conditions. This production line already existed to a lower extent in the years before the sanctions and is now an important economic factor in the Prince Albert area.

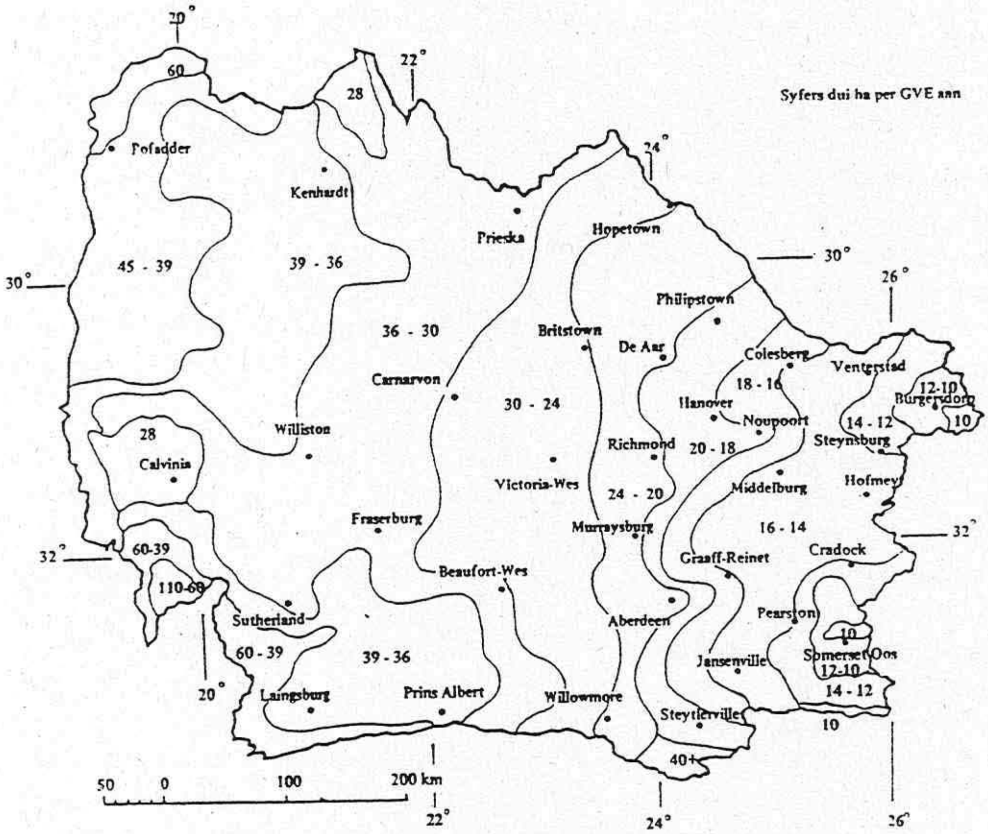


Figure 2.6: Map of recommended stocking rate (ha/Large Stock Unit of 500 kg) (Source: Dept. van Landbou en Water Vorsienning 1986)

The abolishment of the ostrich monopoly of KKK after 1996 resulted in the establishment of small and medium scale slaughterhouses and tanneries, which now enter the export market of ostrich feathers, leather and meat. However, the liberalisation of slaughter houses and marketing boards also led to an abandonment of the associated fees. Therefore, the financing of the agricultural support system collapsed. In addition, the state budget for agriculture has been reduced by 400 Mio. R.

2.4 Population

In Prince Albert district, with an area of 8210 km², the average population density is 1.19 inhabitants/km². Although the white and the coloured population remained more or less constant during the 1980s, indicating out-migration, it increased in the 1990s. Between 1991 and 1997, the white population increased by 8.9% p.a., the coloured by 5.8. % p.a. (compare Tab. 2.4). These growth rates exceed by far the natural population growth of 2.4% for the total South African and 1.6% for the rural population (FAO 1998). It is lower for the rural population due to rural emigration.

Table 2.4: Population of Prince Albert District

	1980[1]	1985[1]	1991[2]	1995[3]			1997[4]
	Total	Total	Total	Town	Rural	Total	Total
White	1,383	1,294	1,301	1,361	339	1,700	2,000
Coloured	7,117	6,702	6,681	5,183	2,817	8,000	9,000
Black	147	33	36	93	7	100	120
Asians	2	0	0				
Total	8,649	8,029	8,018	6,637	3,163	9,800	11,120

Source: [1] Dept van Landbou en Watervorsenning 1986; [2] Population census 1991, data received from Municipality of Prince Albert; [3] estimated by Municipality Prince Albert, [4] estimated by Income Tax Office Prince Albert

As indicated in the interviews, this population growth is probably due to intra-country migration because the Karoo is considered the safest region in South Africa. Farmers from other South African provinces who give up farming due to political insecurity are attracted by the Karoo. Even retired people from Europe settle in Prince Albert.

Between March, 1, 1997 and February 28, 1998, the income tax office received a total VAT revenue of 480,632.16 R from fewer that 500 tax payers, indicating sales valuing 3,433,086.8 R. This implies that each inhabitant of PA bought assets worth 309 R in the course of the whole year, which is pretty low. However, we were told that goods and services are exchanged in kind. Considering the total income tax revenue (1 Mill. R), we can assume that less than 1000 inhabitants with an average income of 55-60,000 R are subject to income taxation (Income Tax Office, pers. communication).

2.5 Actual agricultural and livestock system

2.5.1 Overview

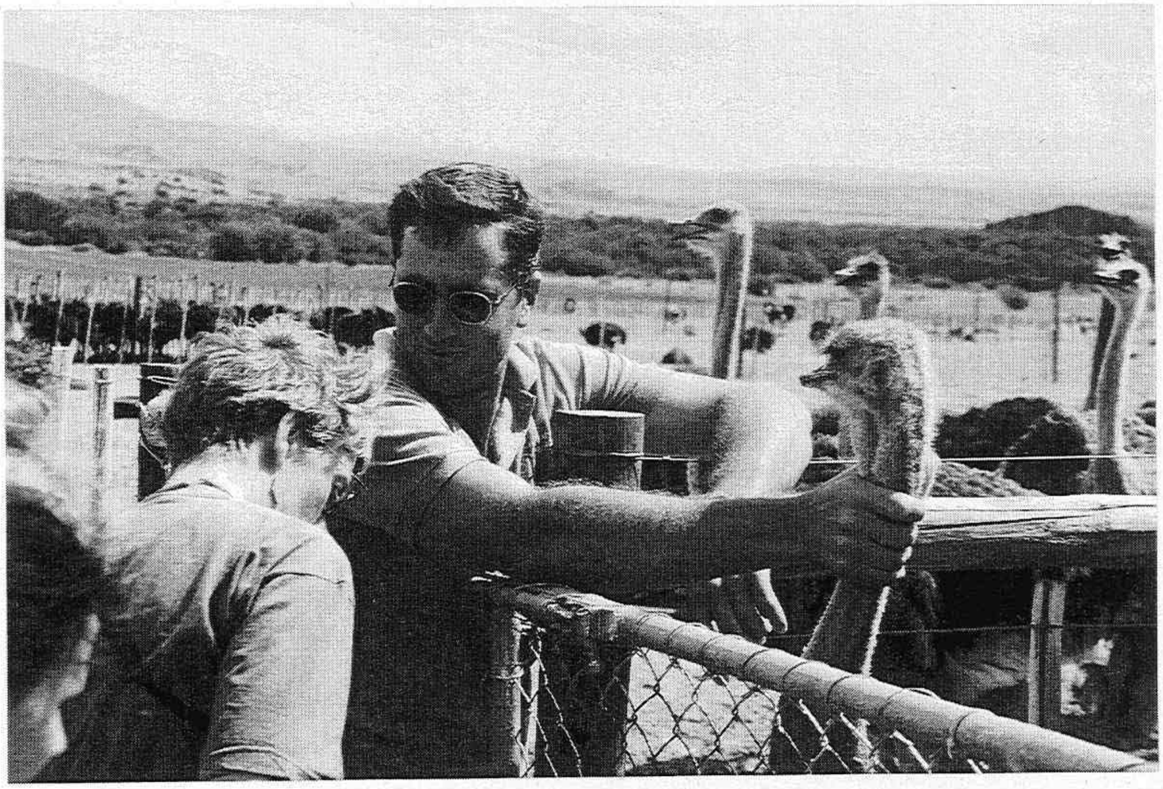
Farm size of the 11 interviewed farmers ranged from 1,400 to 22,000 ha with an average of 9,345 ha (Tab. 2.5). For comparison: 22,000 ha is nearly twice as big as the Addo Elephant National Park with a size of 12,126 ha.

Table 2.5: Farm size and livestock holding (breeding stock) on 11 farms

	n1	n2	mean	SD	minimum	maximum
Farm size (ha)		11	9,345	7,083	1,400	22,000
Number of camps		8	10.3	4.7	2	15
Number of boreholes		7	11.9	8.3	1	25
Livestock holding						
Merino	5	5	1,672	1,690	60	4,500
Dorper	5	5	580	319	102	1,000
Angora goats	4	4	1,400	1,766	200	4,000
Ostriches	7	5	148	103	36	300
Springbok	2	2	93	67	45	140
Cattle	3					
Pigs	1					
Horses	2					

n1: number of farms where the respective livestock species are kept; n2: number of farmers that gave quantitative information about their livestock holding

Picture 13: Dams, mainly in the nearby Swartberg mountains, are used for collecting surface water to grow crops (March 1998)



Picture 14: During an interview near Prince Albert (March 1998)

Instead of the expected sheep dominated system, a very diversified farming system was found with sheep being often not more than a sideline of livestock production in terms of economic returns due to increasing importance of other enterprises (with the exception of two farmers who keep mainly Merino sheep). However, 10 out of 11 farmers kept sheep with an average holding of 1,126. Besides sheep they farmed angora goats, ostriches, springbok (for hunting purposes), cattle, pigs, and horses. More than 50 % of the farmers kept on average 150 ostriches. The pigs held by one farmer served as a food supply for permanent and temporary labourers. One farmer even trained and sold rodeo horses.

The diversity of agricultural production lines includes plant production as well, which above all depends on irrigated land. Access to water is the crucial factor determining possible cropping systems on the farm. Only farmers who have got the chance of using surface water by collecting it in dams (mainly in the nearby Swartberg mountains; compare picture 13) can afford growing the crops listed in table 5.6. Lucerne is grown mainly as fodder for lambing sheep and goats, and for young ostriches. Fruit trees like apricots, peaches and plums were often grown (on 8 out of 11 farms). Half of the farmers produced vegetable seeds, mainly of onion, carrot and beetroot. Furthermore, two farmers cultivated vineyards, one had a red pepper field and another a tobacco plantation. The pepper is exported to Europe for food colouring purposes.

Table 2.6: Irrigation and crop production on 11 farms

	n1	n2	mean	SD	minimum	maximum
Farm size (ha)		11	9,345	7,083	1,400	22,000
Irrigated land (ha)	10	8	55	67	5	200
Number of dams	8	7	0.9	0.6	0.2	2
Water of dam (m^3)	8	5	393,500	295,580	125,000	900,000
Fruit trees (ha)	8	7	9.6	13.1	1	20
Vegetable seeds (ha)	5	4	5.4	3.5	2.5	10
Lucerne (ha)	9	7	17.1	20.3	2	60
Others* (ha)	4	3	16.8	15.0	0.5	30

n1: number of farmers owning or practising the respective issue; n2: number of farmers who gave figures; * others include 2 farmers growing grapes, 1 growing pepper, 1 tobacco

Because there is a need to save water there is a trend to apply more and more efficient irrigation systems, i.e. sprinkler and drip- instead of flood-irrigation where the losses are very high. Normally, they try to avoid using groundwater for irrigating the fields, but one farmer was forced to do so because it had not been raining on his farm for one and a half years. The groundwater which is pumped up by the windmills scattered in this landscape (compare Picture 7) are just used for watering sheep and goats. Everybody agreed that groundwater is more saline than surface water. Above all it is enriched with calcium during its passage through the different strata. Surface water can become saline due to high evaporation. The ground-water level strongly varies from 15 to 50 meters but, according to the farmers, is not seriously affected by the amount needed for livestock.

2.5.2 Sheep production

Two main sheep breeds are kept in the Karoo: wool Merinos and Dorper sheep. The adult weight of a Merino ewe is about 50 kg, that of a Dorper is 60 kg. Breeding strategies for Merinos have undergone several changes, from more coarse wool and and an increase in skin surface in the 1960s to less skin surface and fine wool today. To increase the fineness of the fiber some farmers upgrade their stock with Australian Merinos. The meat-wool ratio of a sheep has changed considerably with declining importance of wool: In the 1940s, the price of a Merino with wool was 10 R, of a shorn Merino 3 R (meat-wool ratio 0.3). Today, the price of a Merino is 250 R, the wool harvest of a sheep (5 kg*26 R) is 130 R (meat-wool ratio 1.9).

With the drop of the wool market price in the 1970s and 1980s, more and more farmers shifted from Merino to Dorper sheep (see Figs. 2.2, 2.4, & 2.5). The Dorper is a pure mutton sheep, bred from local African breeds and British meat sheep. Selection of Dorper is directed at reducing wool growth in order to save shearing costs, because the coarse wool does not gain good prices.

The Dorper has a higher reproduction rate than the Merino, that means 3 lambings per ewe in 2 years instead of just one in the Merino. They also tend to have more twins. The probability of twins rises with the age of Dorper ewes. Thus the live weight of weaned lambs per ewe is higher in dorper than in Merino.

For economic reasons, farmers try to divide lambing into two breeding seasons (spring /autumn) to have a steady output of lambs during the whole year. Pregnancy is controlled by ultrasonic screaning, average gestation lengths is about 5 months. Dorper weaners are mostly sold at the age of 4 months and a weight of 30-40 kg (240-280 R). Merinos are weaned at 4 months and 20 kg, and they are sold at the age of 12-15 months and 30 to 40 kg. Prices are better for lambs than for adult sheep, and an animal is classified as lamb if it has still milk teeth. The first two inscisors appear at 9 to 10 months in Dorpers and at the age 15 to 16 months in Merino. Therefore, farmers profit from the first shearing Merinos before they sell the sheep for slaughter. Ewes of both breeds are used until the age of 6 to 8 years. At this age the teeth of the animals are usually worn down because of the hard fodder and they can not graze sufficiently on the veld anymore.

Dipping against ectoparasites takes place once a year, treatments against endoparasites (e.g. tapeworm, nasal worms, *Fasciola*) twice a year. Because of the arid climate, there is little mortality of young animals caused by parasites. Lamb losses up to 10% until weaning are normal. However, most of the farmers complained about losses of up to additional 40 % due to predators like jackals and rooitcat (*Felix caracal*).

Wool is a traditional agricultural product in the area around Prince Albert. Yield per sheep in the Karoo is about 5 kg. Under better feeding conditions near the coast it can reach up to 6 kg, but it is not as fine and therefore not as valuable. Because of the dry climate the wool has a high clean yield of up to 70%. Lanoline is a by-product of wool production. After shearing, the wool is subdivided into different categories of quality. After periods of stress, e.g. droughts or lambing, sheep produce the so-called hunger wool: the fibres become thin and break more easily. Therefore the quality of the fleece decreases in such situations. Two parameters determine wool quality: length and strength of the fibers. Length ranks from AA (highest quality) to D (lowest quality) as the fibre decreases in length (e.g. D = headwool). Strength or fineness of the fibre ranges from FF (very fine, highest quality), to F (fine), m (medium), s (strong), and ss (very strong, lowest quality). Wool prices vary according to the quality: the price for fine wool (18 μm) is 26 R/ kg, for strong wool (25 μm) 16 R/kg.

2.5.3 Angora goat production

Adult Angora weigh about 40 kg. Lambing period is in August / September. About three weeks before lambing it is advised to provide the does with good pasture, e.g. lucerne, in order to increase the rate of live kids. Angora goats yield about 4 to 5 kg of hair in two shearings p.a. à 22-23 R/kg. The first shearing of babymohair yields prices of up to 132 R/kg.

Goats are dipped before shearing to clean the hair of sand and lice. Reproductive performance and mothering ability are worse than in sheep.

Changing product prices led to a reverse of the average gross margins of small ruminant production in the Karoo. Wool sheep, which had the highest gross margin until 1989, lost importance since 1991, whereas the gross margin of meat sheep and especially Angora goats increased (Fig. 2.7).

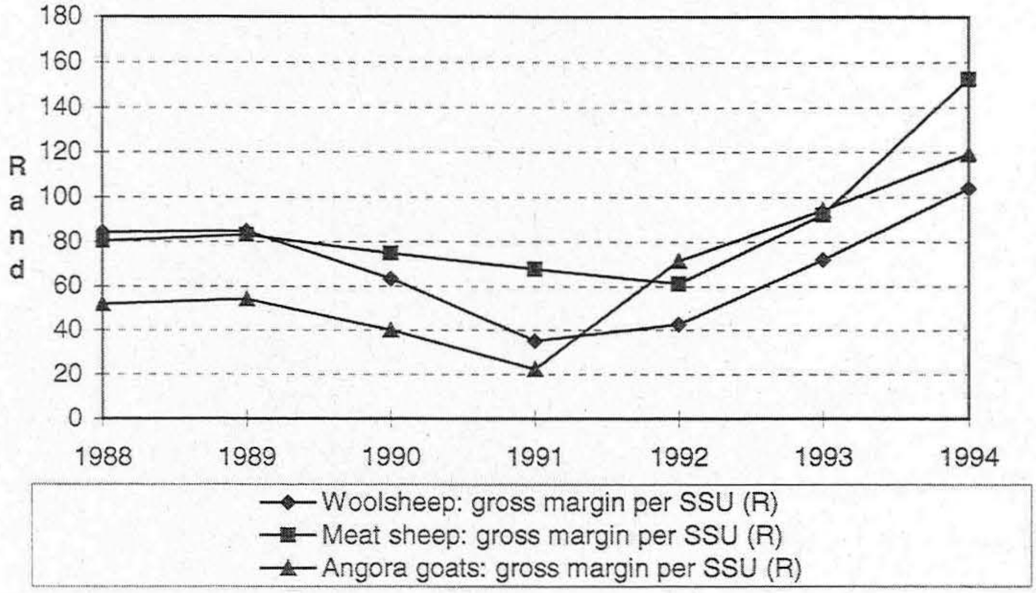


Figure 2.7: Gross margin of small ruminant production in the Karoo
(Source: Direktoraat Landbou-Ekonomie: Studie groepresultate 1993/94. Middelburg KAAP)

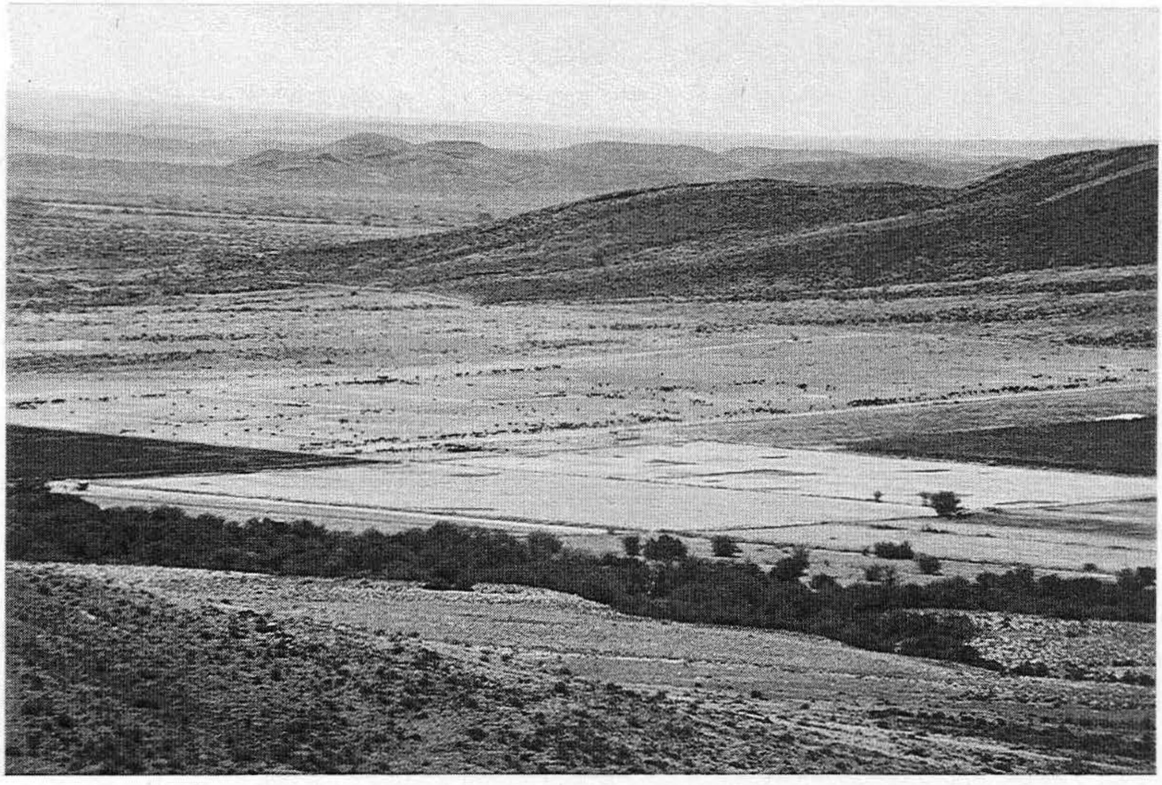
2.5.4 Ostrich production

There are 32 to 40 ostrich farms in the region. Ostriches reach sexual maturity at two years of age and have an adult weight of 110 to 140 kg. Farmers keep twice as many breeding females than males. The breeding period stretches over 3 months, eggs are hatched for 6 weeks. Ostriches are raised from the egg until they are 3 or 14 months old and sold afterwards. Other farmers bought one day old chicks and raised them up to 3 months of age (30 kg), others did fattening from 3 to 14 months of age (85 kg). Then they moult for the first time, and the feathers are easily removed before slaughter. Feathers are exported to Brazil for carnival or used in fashion industry, and skins are used to make leather for leather jackets, handbags, shoes, wallets, and so on.

Losses due to leg problems vary between 3 and 15% from chick to slaughter, other reasons for losses are respiratory diseases and diarrhea. Other farmers reported of 90% losses in certain groups.

The price of one day old chicks declined from 350 R in 1996 to 50 R in 1998. During the boom in the 80s, one breeding pair cost 10,000 R, today the price is 500. Of the 2200 R an ostrich yielded during the high-price period, about 70% was for skin, 10% for feathers and 20% for meat. Ostrich leather has crossed fibres and is very durable. One skin is 10 to 11 sq.feet (130-140 dm²) large, and best grade is priced 150 to 170 R/sq. foot in the USA. Due to the complex structure, tanning of an ostrich skin is more costly than of a cow skin, which is four times larger (about 400 vs. 280 R).

Picture 15: Ostriches on one of the farms where interviews have been made (March 1998)



Picture 16: Ostriches (black dots in the central part of the picture) on one of the farms where interviews have been made (March 1998)

2.5.5 The grazing system

2.5.5.1 Overview

Almost all farmers use the traditional way of shifting the camps, and the wagon wheel system can be regarded as an exception in this area. The farmers had an average of 10 camps with 12 boreholes. Usually the boreholes are at the four borders of a camp and also serve for watering the neighbouring camp. Sheep walk a maximum distance of 3 to 4 km per day. The stocking rate ranged between 5 and 7 ha/ SSU.

Farmers distinguish between "sweetveld" and "sourveld". Plains and valleys in between the hills belong to the sweetveld and hills are called sourveld. This distinction was made because of the different preferences of sheep for the plants and the different nutritive value of the vegetation.

As different as the farms are (due to the various soil types, vegetation, and local variations in rainfall), as different are the grazing systems used by the farmers. However, some major similarities can be stressed. Firstly, most of the farmers rest at least one paddock for one year or more und use the other paddocks for grazing. Secondly, during drought periods they open the gates of the paddocks and the animals spread over most of the farm. Differences occur in the decision when the paddocks are shifted, but in each case this depends on the rainfall:

- Some farmers practise a rhythm of several weeks, e.g. they shift every third or forth week in moist seasons and every sixth week in dry seasons.
- Other farmers look at the conditions of their sheep. However, the farmers, who took the vegetation as an indicator, said that it takes about 3 to 4 weeks in Merino sheep and up to 6 weeks in Dorper sheep before the poor grazing conditions of the veld are visible in the animal. According to them, looking at the animals as indicators of the vegetation would lead to hidden overgrazing.
- A third method is to look at the vegetation whereby the karoobos, *Pentzia incana,* is often used as an indicator species. Other plants as a *Hermannia* species are used as an indicator as well, depending on the plant composition at the different farms.
- The vegetation state in general is seen as the forth possibility of decision making. The condition of the majority of palatable plants is used to decide when the paddock should be changed.

Of course, these four variants are combined in different ways by the farmers. Each of them does it according to his interests. Difference in opinion was obvious in the farmers' decision to shift the camps during the rainy season. One farmer said that he keeps all his flocks in one paddock during periods of rain and rests the other paddocks. Thus, the vegetation on all the rested paddocks has a good chance to grow. In contrast, another farmer shifts his flocks faster during rainy than during dry season. His explanation is that every paddock gets the same good chance for regeneration. However, either reason may be justifiable, considering the different natural conditions on the farms.

2.5.5.2 Impacts of grazing systems

Regarding not only sheep, the different livestock species differ in their impact on the veld. These differences, especially concerning the impact of grazing and trampling, are given in table 7. The Dorper has the highest grazing impact because of its strong jaws and its high mobility and activity. It climbs up the hills and uses the sourveld as well as the sweetveld. In contrast, the Merino does not like to climb and avoids the sourveld. Dorper, as the heavier sheep, feeds more heavily on plants than the Merino sheep does. Therefore, the stocking rate of Dorper sheep should not be more than 80% of the stocking rate of Merino sheep. Even with a lower stocking rate of Dorper, the impact might be the same or more than that of Merino.

In addition to sheep, the veld is grazed by goats and domestic ostriches. Whereas goats can be used for regeneration of the veld because of their low grazing impact ("soft grazers"), ostrich farming can lead to high degradation. Not the grazing behavior but the trampling due to the high mobility and weight of the birds causes the damage of the veld (see Table 2.7). We found two strategies in ostrich farming. Some farmers keep the birds on the veld throughout the year and others only for the three to five months of the breeding season. These strategies are reflected in the impact on the veld. Where ostriches have been kept for longer, especially in fattening paddocks, the result is often bare ground. The area around Oudtshoorn, the centre of intensive ostrich farming, is considered polluted, and sanitary problems in ostriches are increasing.

Table 2.7: Environmental impact of livestock species

	Dorper	Merino	Angora goat	Ostrich
Average live weight of female (kg)	60	50	40	110
Litters per year	1.5	1	1	40-50 eggs
Weaned young per year	1.5	1	1	< 40
Age of offspring at sale (months)	4	< 15	6-12	3 or 14
Grazing impact	+++	++	++	+
Trampling impact	++	++	++	+++
Mobility on the veld	+++	++	+++	+++

+++ very high, ++ moderate, + low

2.5.5.3 Important plants for grazing

Researchers and farmers in the Karoo think that sheep graze stems of Karoo bushes of less than 2 mm diameter, which is used as management decision support. Discolouration of the wounds (grey = old grazed off, straw colour or light greenish = recently grazed) serves as indicator (DU TOIT 1995). About 70% of the floristic composition are less-palatable species (*Pentzia spinescens, Rosenia humilis, Eriocephalus ericoides*). They are grazed to about 1,5 mm stem diameter if enough vegetation is available, but up to > 2 mm under feed stress. During dry seasons, animals graze more intensively. Then plant stems are less succulent and tumescent than during periods of good rainfall, and the measured diameter of the stems declined due to drying up. Plants are overgrazed if animals graze diameters as thick or thicker during the dry season than during good rainfall. Important was the carry-over effect of dry matter: at higher stocking rates or drought conditions, less dry matter is carried over to the next season and consequently the means of browsed diameters increased. This leads to hidden overgrazing. Stems of palatable species (*Limeum aethiopicum, Salsola calluna*) are grazed up to 5 mm, regardless of the stocking rate, due to low abundance and high palatability (DU TOIT 1995).

In the interviews, the farmers roughly ranked the palatability of plants for sheep or the preferences of the animals. Their answers were influenced by the differences in vegetation composition on the farms and by the farmers' differing interest for the plants on their veld.

Nenax microphylla (daggapit), *Tetragonium sarcophyllum* (kinkelbos) and *Limeum aethiopicum* (koggelmandervoetkaroo) are mentioned as most preferred plants. Ranked as palatable are the shrubs *Osteospermum sinuatum* (bietou), *Pentzia incana* (karoobos), and *Ruschia spinosa*. An interesting plant is *Thesium lineatum* (vaalstorm), growing in the washes of Tierberg farm too, which is given as palatable by some farmers and as toxic by others. The reason for this is the parasitic strategy of this species. Whether the plant is toxic or palatable depends probably on the host species that is parasitised.

One farmer with a veld comparable in species composition to the study sites at Tierberg and Sandrivier gave the information that sheep feed first on palatable succulents and annuals (softveld), then on non-succulent shrubs and latest on grasses (hardveld).

Angora goats are the domestic animals which browse on *Acacia karroo*, a tree occurring in drainage lines. They are considered as soft browsers on the veld because they browse also larger shrubs or trees.

The last group of plants can be used as an indicator of degradation when dominating the veld. The first is the unpalatable *Pteronia pallens* (armoedsbos) that was found on farms at the plains near Tierberg and Prince Albert. *Chrysocoma ciliata* (bitterbos) occurs on almost every farm. This plant is responsible for lambs born hairless if eaten in high amounts. According to some farmers, adult sheep can loose their hair, too. *Galenia africana* (Geelbos), that indicates former ostrich farming, was found on a farm south of the Swartberg Mountains. The shrub is poisonous, sheep get stomach problems and goats can die. *Atriplex* ssp. (salt bushes) are used as drought forage. They were introduced from Australia and invade disturbed grounds.

Introduced weeds represent a danger of altering the vegetation composition negatively. Some are able to disperse fast, like *Xanthium spinosum* (boetebossie) introduced from South America. It's burred fruits mechanically damage the wool. Another easily dispersed weed is the parasitic *Cuscuta campestris* (dodder). This chlorophyll-less, leafless plant growing mostly on Lucerne (*Medicago sativa*) was introduced from Europe and is now widely distributed.

2.6 Recent social and economic changes

The strong export orientation today, the rising standard of living and the low prices for agricultural products require a new form of organisation. As a reaction, the farms in the area around Prince Albert seemed to be in a transition state from family farming to modern agricultural enterprises. The traditional sheep dominated system is in most cases economically no longer sufficient. According to the farmers, it is necessary to keep about 1,200 ewes on at least 6,000 hectares of veld. One generation before the ratio was 800 ewes on 2,000 hectares. In order to cope with the economic pressure, diversification of the production is inevitable. This development becomes obvious if one looks at the high average farm size (9,345 ha) and small ruminant holdings, and from the high area of irrigated land. According to these figures, average farm size has doubled within the last 10 years (see Tab. 2.3). Since land area can not be enlarged, this development implies a high proportion of farmers that gave up farming, and frequent sales and re-sales of land. It is quite common for one farmer to rent the land of others or to run more than one farm in order to maintain economic competitiveness. Out of the 11 farmers interviewed, 5 had bought their farm, 4 had inherited it or acquainted it by marriage, 1 had a combination of inheritance and purchase and one a combination of purchase and rent. Four of the interviewed farmers (36%) managed between two and four farms. This leads to a concentration of land and capital.

Frequent sales of farms lead to land speculation and very high prices per ha veld or irrigated land. Farmers are not the only actors on local land markets. As mentioned above, migration into the Karoo has gained importance during the last years. A very recent development is land speculation. Both has an impact on land prices. Due to increase in land prices and diminishing returns from small ruminant farming, farmers cannot enlarge their farms easily, because they cannot compete with the speculators. Since veld is used by small ruminants, farmers usually calculate the maximum land price in revenue per small stock units. The price per ha then depends on the stocking rate given by the Dept. of Agriculture for the region (see Fig. 2.6). Recently paid prices were 10,000 R per ha of irrigated land, and 150 to 160 R per ha veld (900 R/SSU). In order to make a profit, one should not pay more than 60 to 70 R per ha veld. However, farmers also reported that people had paid up to 250 R/ha veld or 2000 R/SSU. Monthly rent for veld is around 1R per ha.

Speculators might pay 1 Mill. R for an average 6200 ha farm producing an annual brut revenue of 150,000 R, which will never pay off by sheep farming. Speculators buy farms to avoid income tax of up to 48%, which is calculated as the average of all incomes. Farmers reported of two non-farmers who own up to seven farms each. They keep only a few animals on the farms in order to make economic losses. Since they are not interested in farming, the farms become neglected, which means that they externalise the costs of their tax evasion. Even if labourers live on the farm, they do not care as a farming owner would do, and weeds and predators spread out from these farms and threaten those neighbouring farmers who still depend on farming. The farmers mentioned this neglect of farms and the game richness of the Natural Reserve in the Swartberg Mountains as major causes of the increase in predators for several years. The reported recent increase in lamb losses was said to be due to predators. These losses are lower with farmers who confine ewes with lambs to smaller camps near their houses, which is more labour intensive. In order to reduce the number of absentee farm owners the farmers suggested, that a farm should only be considered as a farm for income tax calculation if the owner is living on it. Otherwise, it should be considered as speculation and taxed much higher. However, this would also apply to those farmers managing more than one farm.

Increase in land prices has another aspect, since the Government is discussing a new land tax law. Rural land tax is considered as a means to raise rural local government revenue, and as a policy instrument to complement a non-confiscatory land reform programme (Dept. of Land Affairs 1996). The farmers feel threatened because the Government is under political pressure to re-allocate land. Although the KATZ Commission recommends further investigations on the feasibility and possible implementation of such a tax, farmers fear that if the land tax would be calculated based on land sales, assuming that land prices reflect the economic profit out of a farm, but farms are sold at prices exceeding any economic return, then farmers would have to pay land tax of more than 25% of their returns. The increase in land prices around Prince Albert is exceeding the average index of land price in sheep grazing regions, which is below the average of South Africa (Fig. 2.8). One farmer reported that the ratio between land price and return per livestock unit to be kept per ha had remained constant for 90 years in other South African regions, e.g. Xhosaland.

Another consequence of this development is a depopulation of the rural area, related to a decline in rural infrastructure. These two facts act like a vicious circle: depopulation accelerates the decline in infrastructure and vice versa. This way, a development of draining of the rural areas is created.

The number of inhabited farm houses serves as an indicator for depopulation and the related problems. Out of 98 farms located in Prince Albert Police district, 22.4% are completely uninhabited, 4.1% are inhabited by labourers, but managed from elsewhere (PA Police, pers. communication). In Klaarstom Police district, about 48% of all farms are not inhabited.

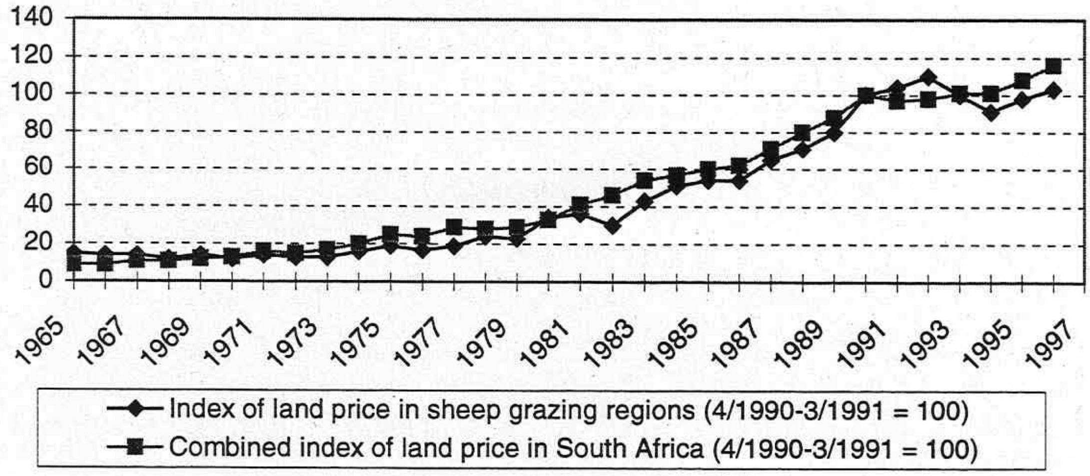


Figure 2.8: Indices of land prices in sheep grazing regions and in the whole of South Africa (weighed average)

Farmers adapt to these recent developments by organisational changes. There is a tendency of farmers forming trusts and giving up the old family farming system due to economic and administrative reasons. Out of the 11 farms, 7 were family farms with coloured labourers, 3 had employed managers besides the farm owner, and 1 had formed a trust.

In the mid 1980s, more farmers in Prince Albert were grouped as more or less innovative than the average of farmers in the Karoo, but their degree of organisation was low (Tab. 2.8; Dept. van Landbou 1986). However, after 1994 the number of farmers being member of the Agricultural Union sharply increased (Tab. 2.9), because they see the necessity of a better organisation and representation.

Table 2.8: Estimated progressivity of farmers (% farmers per progressivity class) (Source: Dept. van Landbou en Water vorsienning 1986)

	High	Medium	Low
Karoo	23	51	26
Prince Albert District	30	40	30

Table 2.9: Organisation of farmers in the Agricultural Union, PA District (in %) (Source: Dept. van Landbou en Water vorsienning 1986)

1996	1997	1998
18	28	52

2.7 New ecological problems

The ecological problems of the Prince Albert area are changing due to the declining economic importance of sheep production. The income of the farmers is no longer completely dependent on the veld, which makes them loose interest in it. The veld has been damaged by overutilisation due to livestock breeding in the last 100 years. The reduced intensity of sheep production may improve the condition of vegetation, but sometimes reduced intensity means neglection. Such a careless attitude might also damage the vegetation, e.g. if sheep are left in the paddocks for too long, or if weeds such as *Prosopis* spp are no longer controlled. *Xanthium spinosum* is likely to damage wooled sheep with resulting losses to sheep farms.

Severe problems arise from ostrich production. The high stocking density in the feeding lots together with the high trampling impact of the birds lead to the complete destruction of vegetation. The missing plant cover makes this areas prone to wind and water erosion. Moreover, the excrements of the birds accumulate in the soil because of the climatic conditions in this area, which results in high contents of nitrate, phosphorous and salts in the soil which inhibit plant colonisation after the agricultural use of these sites is abandoned.

The production of irrigated annual crops, e.g. for vegetable seeds, is comparatively new in the Prince Albert District. Cropping of annual crops leaves the soil without ground cover for a certain time of the year. It is yet unknown if this might have an accelerating effect on wind and water erosion.

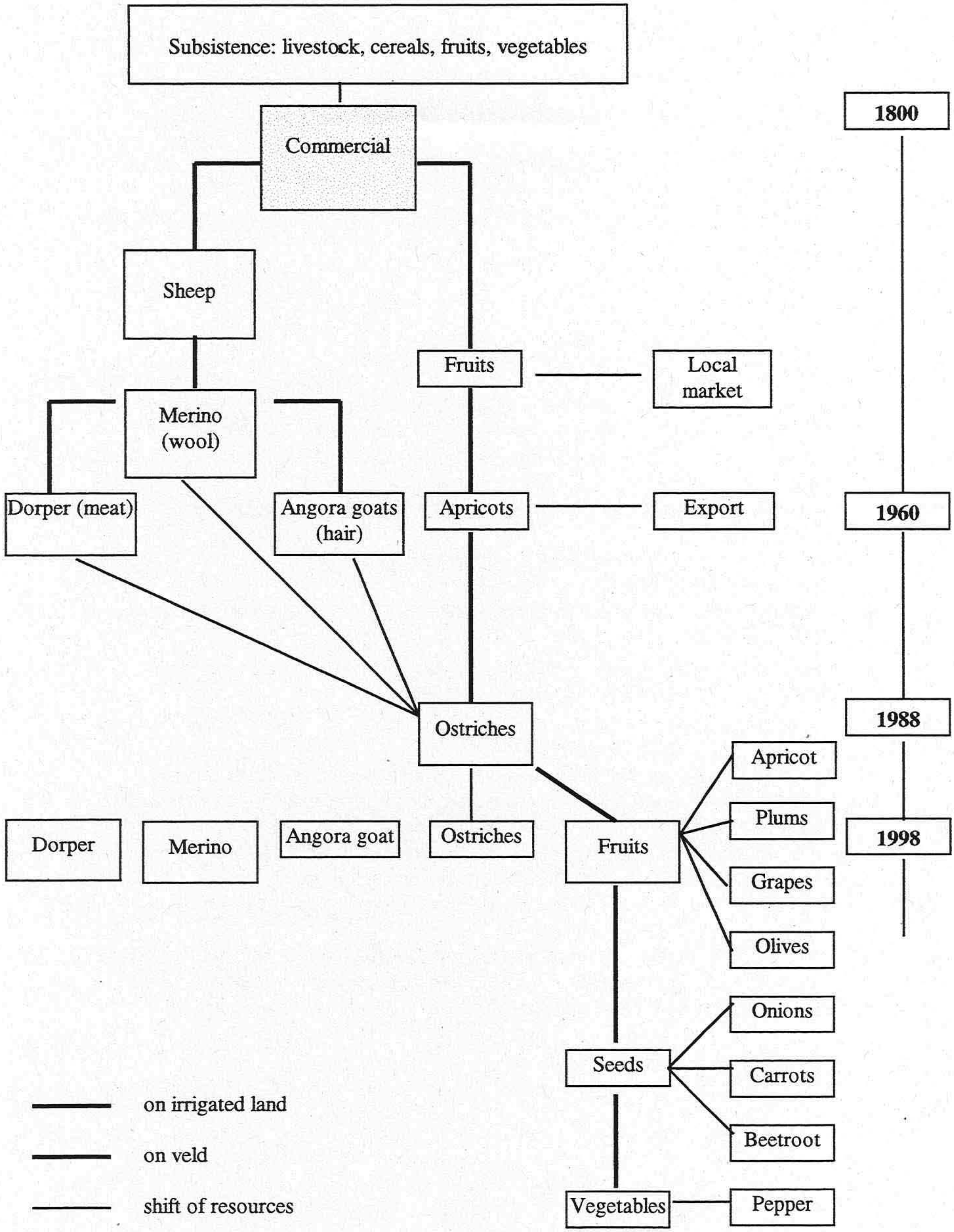
2.8 Conclusions

The development of the livestock sector in Prince Albert District is a good example of a farming system in transition. It becomes more dependant on external economic and political factors than on internal ecological conditioning ones. The region is in a transition state from family farming to modern agricultural enterprises, from farmers who have a relation to the land and feel responsible for it to modern entrepreneurs who cultivate any product if they have the technical possibility and the market is good.

Ecological problems of today are inherited from past management and overgrazing under a small ruminant dominated production system. Intensification especially of the cropping system on the one hand and reduced intensity of the livestock sector on the other hand will probably create new environmental problems yet not foreseen, but not taken into consideration due to economic pressure.

The study gave also some hints about possible future social problems within the community due to land speculation, rural depopulation, and neglection of farms resulting in a spread of predators and weeds which threaten those farmers still depending on small ruminant production.

Figure 2.9: Chronology of agricultural production in Prince Albert District



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Appendix The history of the Sandrivier Farm

The history of the Sandrivier Farm is representative for many farms in the area. Within the last hundred years agricultural production changed from traditional subsistence farming to a modern, market-oriented system (Fig. 2.9).

Sandrivier Farm today covers an area of 7000 ha. Though changes in size and the exact year of foundation are not known, the farm, like most of the farms in the area, probably was founded at the end of the 18th century during the first boer-treks. Over the last hundred years the farm had nine different owners.

Up to the 1920s, nine to ten white and coloured families lived on the farm, on subsistence farming only, which included vegetable and cereal production. Donkeys, cattle, sheep, goats and horses were kept. Livestock was herded by shepherds. To prevent losses caused by predators the animals were kept in kraals during the night.

During 1920 to 1930 the first boreholes were drilled and fences built. The owners introduced Angora goats and Merino sheep to Sandrivier Farm at a high stocking rate (about 3 ha/SSU).

From 1945 to 1960, fence building was enforced and the whole area of the farm divided in six camps. The pasture management changed to a "transhumant" system with summer pastures on the grasslands north of Prince Albert and winter pastures on bushveld on the Sandrivier Farm. In these years the stocking rate on Sandrivier Farm was exceptionally high: 2.3 ha/SSU during winter. Despite the grazing rest during summer, the vegetation could not recover from the high grazing impact. Severe vegetational degradation was the result.

During the 1960s, the damages in vegetation forced the farmer to take action by destocking the sheep and giving up goat breeding. Fence building continued and in the end of the seventies the farm was divided into 32 camps. After that no more new fences were build. During the years of fence building the veld was not grazed for one and a half years which gave the vegetation at least a certain time to recover.

During the 1970s, the farmer followed the Department of Agriculture's recommendations of a stocking rate of 7 hectares per sheep. Moreover, a change in agricultural production took place. Instead of wool production with merino sheep they started meat production with dorpers and boergoats. With a combination of sheep and goats all different layers of vegetation can be used.

In 1987, the farm was sold again. With a new owner the situation changed once more. To improve the condition of vegetation, soft-grazing angora goats were kept and sheep production was given up.

The farm was sold again in 1996. The actual landowner is absent and only keeps a few ostriches on the camps.

Chapter 3

Geology and Geomorphology of the Karoo region and the study sites near Prince Albert

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[Text and figures of this chapter summarise the descriptions of VISSER (1986), THERON (personal communication in 1998) and information from geological maps (GEOLOGICAL SOCIETY OF SOUTH AFRICA, 1985; DEPARTMENTS OF MINES, 1979).]

3.1 Geological history and lithology of the Karoo region

The area under investigation (Prince Albert) lies from the geological point of view at the border of a vast sedimentation basin, the southern and south-western parts of which are now deformed, folded, and elevated by the cape folding system (Fig. 3.1).

Early sedimentary sequences of Archaean age (2000 to 3000 million years ago) are exposed in the north of the Karoo. Between 2000 and 1000 million years ago sedimentation and vulcanism occurred in the north-western Cape and southern Namibia. These depositions have been destroyed by tectonic action at the end of the period resulting in metamorphism and intrusion of a batholith, forming the Namaqualand complex of the north-west. In the precambric period (800 to 600 million years ago) eroded material of the Namaqualand complex was sedimented in a north-south directed basin under shallow to deep marine conditions. This forms the Nama sequence which is exposed also in the region of Oudtshoorn in the south of the Swartberg mountains. The Cape granite of the Kuboos pluton, which is exposed near George and around Cape Town, also intruded at the end of the protoerozoic period. However, it is about half as old (≈ 600 million years) as the Namaqualand complex.

With a bigger break during the Carboniferous, 450 million years ago more or less continuous sedimentation into the Cape-Karoo Basin started in Silurian until the Permian and formed the Cape Supergroup (Table Mountain-, Bokkeveld- and Witteberg Group) with a thickness of about 7,000 m, as well as the Karoo Sequence (Ecca- and Beaufort Group), being approx. 6,000 m thick.

The sands of the whitish-grey quartzitic sandstones of the Table Mountain Group were deposited on beaches during a marine transgression. The Bokkeveld Group is an alternation of sandstones and shales deposited during cyclic transgressions and regressions most probably as a result of tectonism. The material was transported from mountains in the north and deposited in extensive deltas (Fig. 3.2). During more stable conditions in the source region, the beds of the Witteberg Group have been deposited in deltas, beaches and under shallow sea conditions. Mainly quartzitic and feldspathic arenites, feldspathic grits, thin conglomerate layers, siltstones, shales, and diamitites form the rocks of this group.

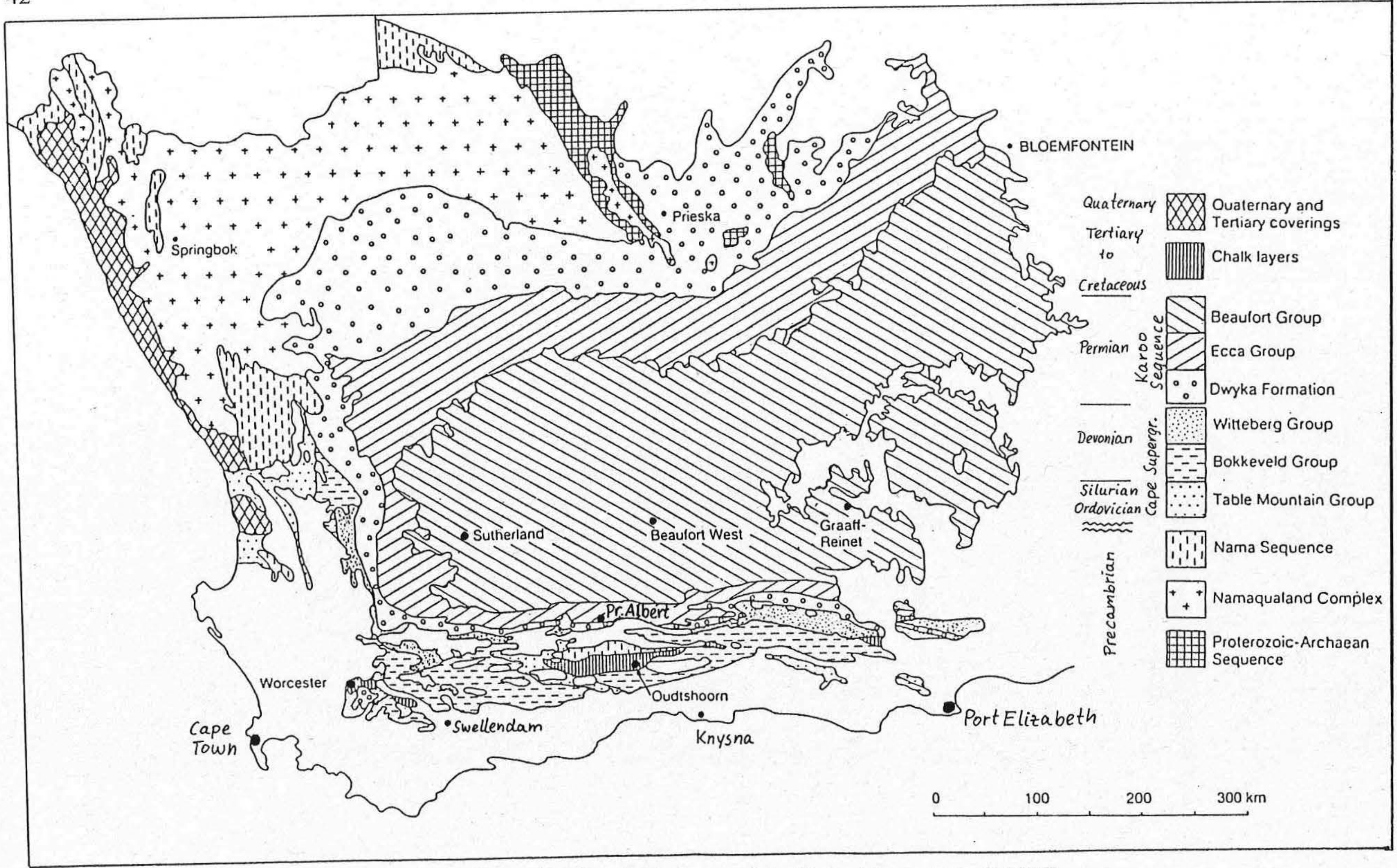

Figure 3.1: Generalized geological map of the Karoo biome (VISSER 1986)

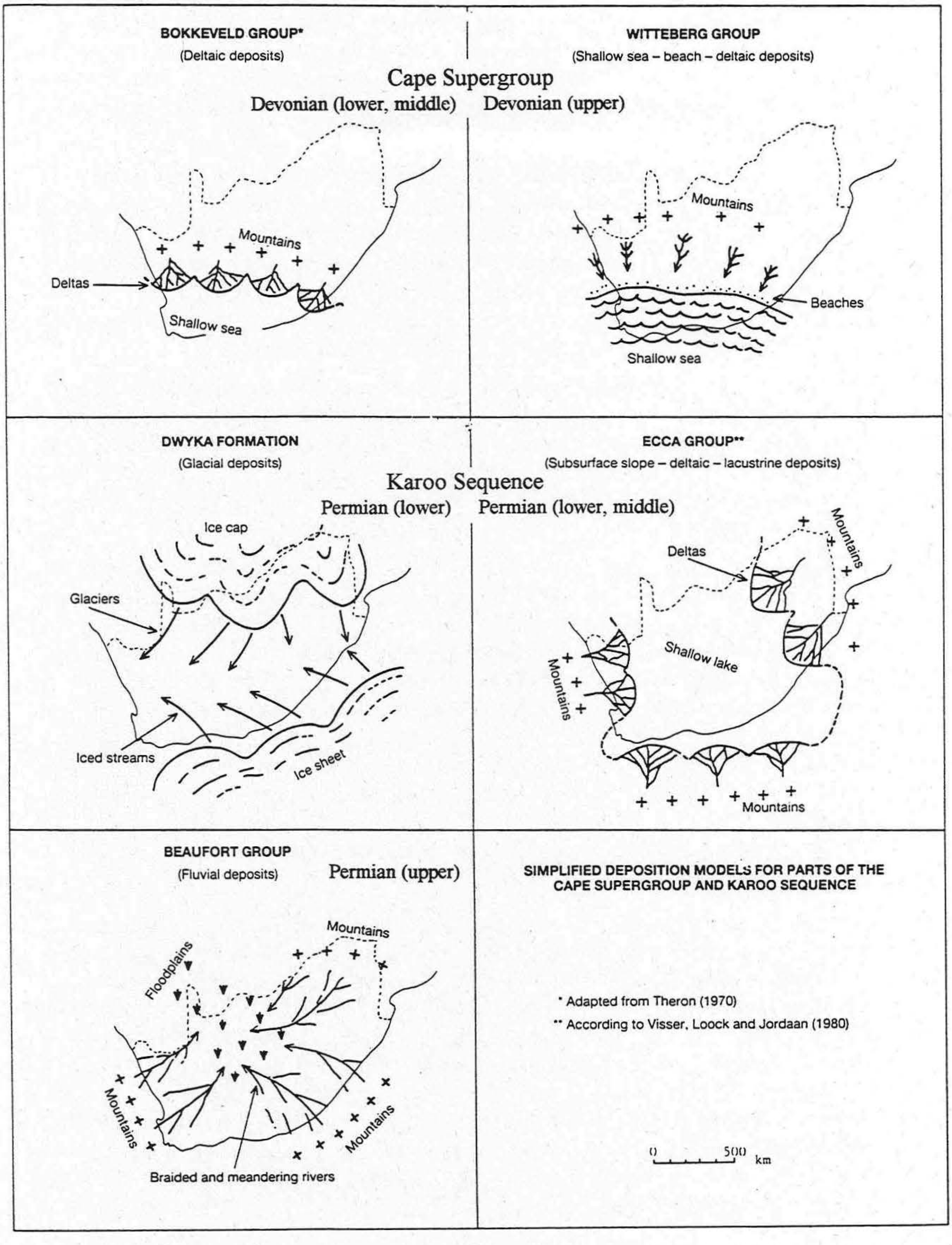

Figure 3.2: Simplified deposition models for parts of the Cape Supergroup and Karoo Sequence (VISSER 1986)

After deposition of the Cape Supergroup an uplift and erosion interrupts sedimentation into the former Cape basin. The unconformity between the Cape Supergroup and the Karoo Sequence is marked by the about 750 m thick Dwyka Formation of a tillite with blue-grey argillaceous matrix and angular to subrounded clasts of predominantly gneiss, granite, quartzite, diorite and lava. The ice-rafted material was deposited from glaciers of an ice cape in the north and from iced streams of an ice sheet in the south (in that time the pole moved over southern Africa).

After the glaciation the melted water was collected in a large shallow lake and during the cool conditions with luxuriant vegetation, the black clays and muds of the Ecca Group were deposited. In that time, deformation of the Cape Supergroup has already started by orogenesis south of Africa (at present part of Antarctica) and mountain forming processes moved from the south closer to Africa. Therefore, the more lacustrine sediments of the Ecca group changed to fluvial deposits of monotonous alternating argillaceous and arenaceous beds of meandering streams on large floodplains of the Beaufort Group.

The deformation of the Cape Supergroup reached its northern limit during the Triassic, and the lower part of the Karoo Sequence in the south was also folded. Also during the Jurassic the Karoo dolerite intruded up to the Beaufort Group forming the striking plateaus near Beaufort West and Graaff-Reinett, which are visible today. During Cretatious the break up of Gondwana started and halfgrabens (intermontane basins) occur in the present coastal regions which were filled with erosion material from higher elevated areas.

Sedimentation of the Cretaceous beds was followed by a long period of erosion. The drainage was now directed towards the south and with the elevation of the folded regions, possibly during the early Tertiary, deep valleys were incised. During the Mio-Pliocene a rise in sea-level occurred and the transgression caused a rise in the base of erosion, which led to aggradation of the rivers. The river valleys were then filled with gravel and debris. A later drop in sea-level associated with the Pleistocene glaciation lowered the erosion base again and led to the incision of the filled valleys, with the result that only terraces are left today. Later rises in sea-level, however, led to transgressions and coastal sands were deposited some distance inland. At present there is a regression and some of the low-lying areas are now filled with aeolian sand.

3.2 The study sites east of Prince Albert

All study sites (Platberg [Tertiary terrace], Sandrivier study sites, Tierberg research station) are located in the generally shallow Sandrivier Valley about 5, 17 and 24 km east of Prince Albert (compare chapter 1). The strictly east-west oriented valley is a fold-tray (syclinal-valley) filled with quaternary material, which marks the southernmost destruction limit of the Permian Dwyka Formation and Ecca Group, influenced by the cape folding system (Fig. 3.3). In the south, the members of the Dwyka Formation and Ecca Group strike out as a falt-shank in narrow strips on the steep diping (60 to 70°) sandstones of the Witteberg Group, which forms the Oukloofberge. The northern border of the valley is formed by a ridge (fold-saddle) were rocks of the lower Ecca Group (mainly shales) and tillite of the Dwyka Formation crop out. North of the Tierberg research station, sandstones of the upper Witteberg Group forms the ridge (see crosssections in Fig. 3.3).

The valley bottom is highest (≈ 900 m a.s.l.) near the road from Meiringspoort to Beaufort West, were a valley-watershed is developed and drainage occurs to the east via the Trakarivier and to the west via the Sandrivier. Both are non-perennial rivers. The valley bottom of the Sandrivier has an inclination of about 0.7 % in east-west direction and of about 3 % in north-south direction (north of the Sandrivier).

Between Prince Albert and the road from Meiringspoort to Beaufort West three north to northeast-south to southwest oriented tributaries of the Sandrivier break through the ridge in the north of the Sandrivier, but only the Tierbergsrivier reaches the area were rocks of the Beaufort Group are exposed. Therefore the main source for the quaternary deposits in the valley are areas with exposed rocks of the Ecca Group. The fluvial transport in the northern part of the valley acts generally in east-west direction with the Sandrivier and in northeast-southwest direction with its tributaries and along the valley slopes.

A special situation is given for the Tierberg research station. The station is located between the Tierberg farm and the Sandrivier. At the Tierberg farm whitish-quartzitic sandstones of the Witteberg Group crop out. In the south of the Tierberg farm, a pleistocene terrace is developed between the sandstone outcrops and the shale ridge, which here is partly degraded but generally forms the northern border of the valley. Therefore blocks of sandstones and also of tillite have been transported to the area of the research station. Sandstone and tillite boulders at the topsoil of the research station are the obvious marks of different soil substrates in comparison to the Sandrivier study site.

Also an outstanding situation is given with a tertiary terrace 5 km east of Prince Albert (Platberg). The very plain terrace, some ha in extend, occurs nearly 100 m above the valley bottom in about 700 m a.s.l. Some remnants of terraces of similar age and extend occur at the southern slope of the Swartberge near Meiringspoort. There the terraces transgrade over folded sandstones of the Table Mountain Group and rocks of the Precambrian Kangoo Group at about 900 m a.s.l. The differences in height indicates uplifting processes of the Swartberge during Tertiary.

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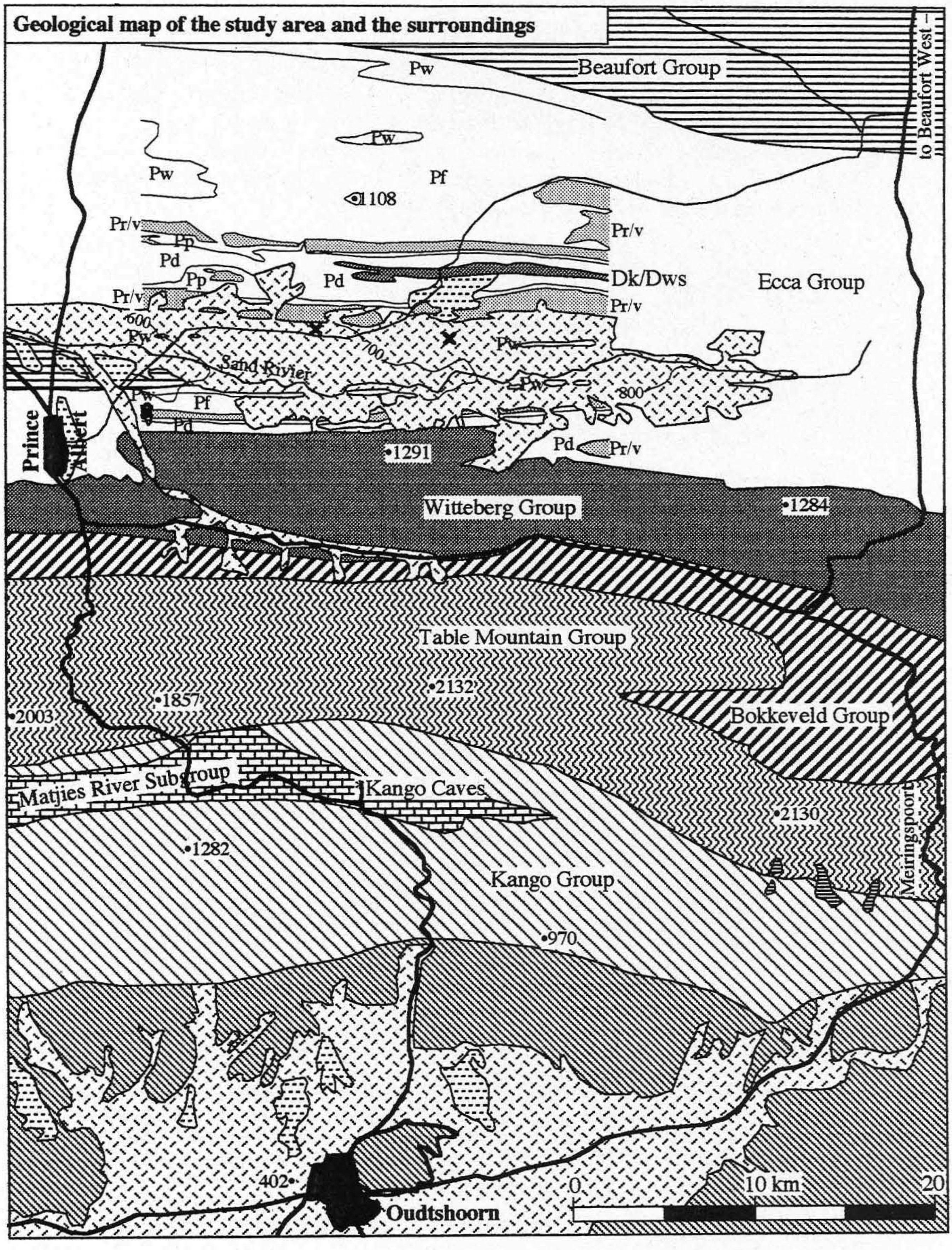
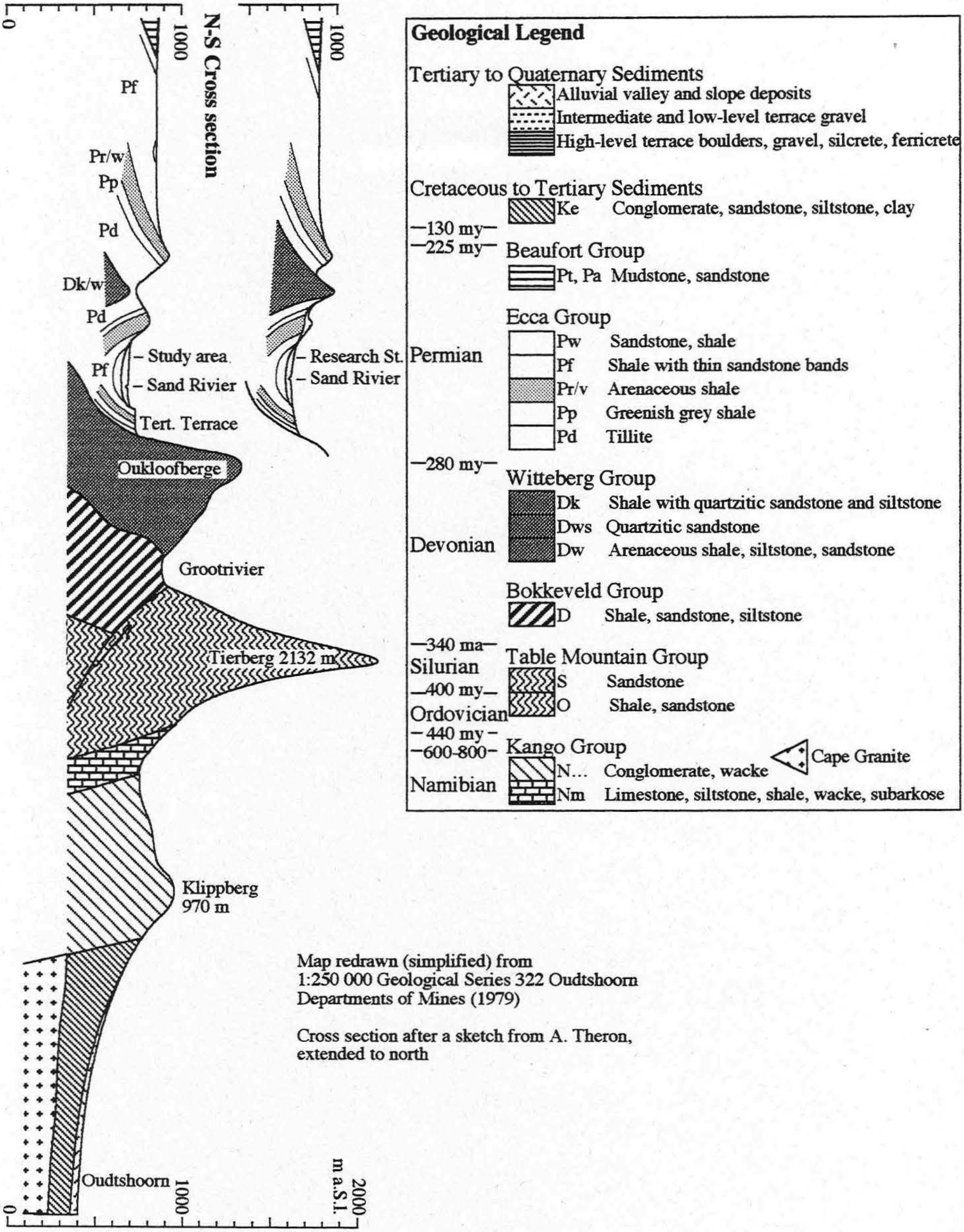


Figure 3.3: Geology of the research area



Map redrawn (simplified) from
1:250 000 Geological Series 322 Oudtshoorn
Departments of Mines (1979)

Cross section after a sketch from A. Theron, extended to north

Chapter 4

Soils of the study areas

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4.1 Introduction

Soils are one of the natural and indispensable foundations for all living organisms (man, animals, plants). They fulfill various functions, like supply of living space for flora and fauna, reservoir of nutrients and water, filter for preserving the ground water, place for settlement and trade, and many others.

The soils of the study area near Prince Albert are mainly covered with plants which are either used for grazing or are at least a result of grazing activities. Thus, here as well the soil has a key function as a basis of agricultural production. Knowledge about soil properties is a basic precondition to achieve and judge on sustainability of land use practices.

Tasks of the soil science group have been:

- description of soil properties,
- classification of the soils,
- ecological evaluation of the soils and
- comparison and investigation the heterogeneity respectively homogeneity of the soils in and between the different study areas.

Special care was given to the water budget of the soils. For this,

- the infiltration rate was measured near different soil profiles and, by chance,
- the wetting depth of an extraordinary rain event was measured on different sites.

The related topic of "root density" has been dealt with in more detail and is treated separately (see chapter 5).

4.2 Locations (sites) of soil profiles

For comparison, soils of different locations have been investigated. Most observations have been made in Sandrivier and Tierberg area. In addition one soil was also investigated at the Platberg because of its extraordinary geomorphic position. The locations of the investigated soils are shown in Fig. 1.x (in chapter 1).

"Sandrivier" area. The "Sandrivier" area represents grazed conditions. The soil profiles have been excavated in different distances from the waterpoint (sites B, C, D, E), according to the general pattern, which formed the basis of interdisciplinary co-operation within the excursion. One additional profile was situated on the foot slope of a shale hill (Put the Kop, 776m) at the northern border of the study area, and one other additional profile was situated on the drainage line (Dikrivier) near the waterpoint.

"Tierberg" area. "Tierberg" area represents "natural, non-grazed" conditions (see chapter 1). Only one profile has been excavated within the area itself near the research station. A further profile was analysed in the direct vicinity in a drainage line.

"Platberg" area. To understand the landscape ecological interactions and to get hints on historical developments a further profile on the top of an tertiary plateau (Platberg) near Prince Albert has been analysed (exclusively by the soil science group).

Table 4.1: Names and localities of investigated sites

Sandrivier area	~ 18 km (road) east-northeast of Prince Albert	
SR site B	50	m west of waterpoint
SR site C	150	m west of waterpoint
SR site D	350	m west of waterpoint
SR site E	800	m west of waterpoint
SR site sh	~ 500	m north of SR site B
SR site dl	~ 200	m southeast of waterpoint
Tierberg area	~ 27 km (road) east-northeast of Prince Albert	
TB site rs	~ 20	m west of hut of the research station
TB site dl	drainage line near the northern fence of the research station	
Platberg area	~ 5.5 km east-northeast of Prince Albert	
Pb	~ centre of the high plain of the Platberg	

4.3 Materials and methods

4.3.1 Soil description and analysis

As precondition for all further work, soil pits had to be dug to create and have access to the profiles. Soil mapping with an auger was impossible due to the very dry and therefore very hard soil conditions. The soil profiles had to be characterised according to the German "Kartieranleitung 4" (AG BODENKUNDE 1994) and a field manual (JAHN 1997). Designation of horizons was performed according to the FAO-UNESCO classification (FAO-UNESCO, 1994), and field and laboratory tests (bulk density, pH, electrical conductivity) have been made for detailed characterisations of the soils.

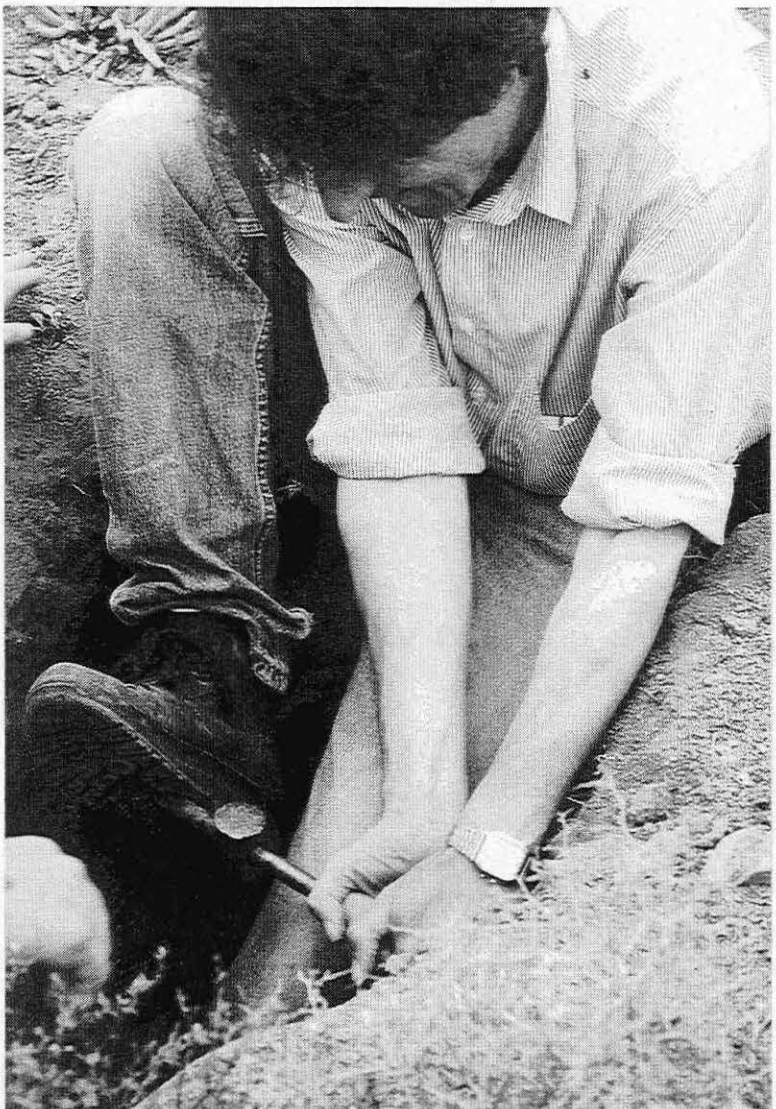
The following steps have been undertaken after AG BODENKUNDE (1994) and JAHN (1997):

- delineation of each horizon according to optical features, like changes in colour, stone content, and texture;
- estimation of stone content;
- soil texture analysis based on the "fingertest";
- soil colour description by comparison of the soil colour (moist) with the Munsell colour chart;
- estimation of content of organic material, using colour, clay content and pH;
- estimation of calcium carbonate content by using 10% HCl;

- estimation of soil moisture by using optical criteria (change of colour after wetting the soil);
- description of soil structure by using a determination key;
- analysis of bulk density by taking soil samples ($100cm^3$) and drying them at 105°C for 3 hours in an oven (bulk density [g/cm^3]=mass of soil after drying [g]/soil volume [cm^3]);
- measuring pH in 0.01 M $CaCl_2$ with a pH-meter.
- quantification of root occurrence;
- estimation of available water capacity (derived from the results of stone content, texture, bulk density and content of organic matter);
- estimation of cation exchange capacity (CEC; derived from the results of stone content, texture, pH and content of organic matter)
- measuring electrical conductivity as an indicator for the salt content in a 1:2,5 soil:water suspension, results estimated to EC (exchange capacity) of saturation extract according to the water capacity.

[The laboratory tests for the determination of pH, nutrient content, and electrical conductivity were made by the nutrient group, see chapter 6 by KAHLE et al.).]

The soils have been classified according to the FAO-system (FAO-UNESCO, 1994). Based on the measured or estimated soil parameters (see above) the evaluation of ecological site qualities (water budget, nutrient budget) was done on whole soil basis down to the rock or to 1m depth.



Picture 17:
Removing the auger to get hold of a sample has mostly been very hard work (March 1998)

Picture 18: As precondition for all further work, soil pits had to be dug to create and have access to the profiles ("Sandrivier", March 1998)

4.3.2 Water infiltration

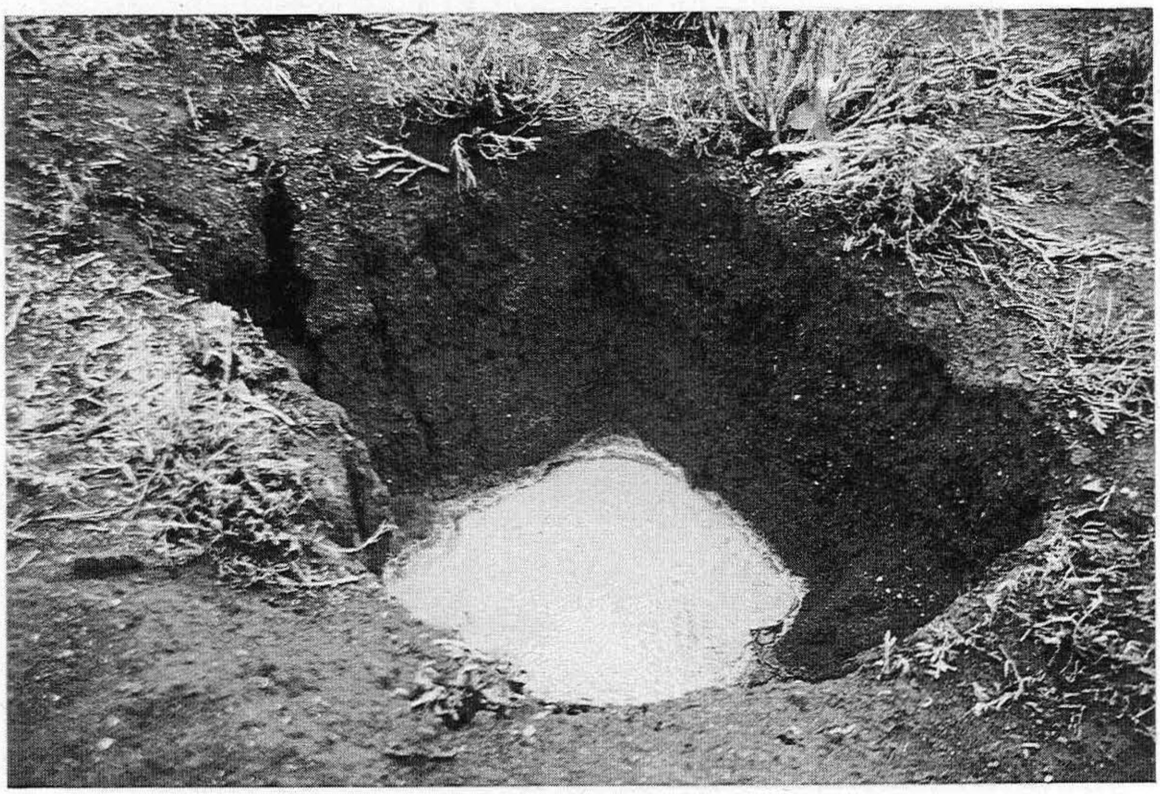
The infiltration rates near every profile have been investigated "between" two plants and on the "plant hills" in the "Sandrivier" study area. Therefore, in several replications, we measured the time, which was needed for one centimetre of water in a cylinder (of 7 cm in diameter) to infiltrate into the soil.

In addition, after a rain event of about 30 mm within two days (26/27.3.1998) we used the opportunity to measure the wetting depth in the "Sandrivier" study area. For this measurements ditches have been opened about 1.2 to 1.5 m wide and about 0.5 m in depth between two plants. The clearly visible wetting depth was measured in distances of 10 cm. The uneven soil surface, especially the height of sandy material below plants was measured with the help of a horizontally fixed strip.

4.4 General results and discussion

4.4.1 Soils and soil properties

The investigated sites are generally exposed in southern directions. The inclination - with the exception of "SR site sh" – is low. The soils have been developed from various rocks (Tab. 4.2). The geological characterisation was done by comparing the field observations with the geological map (GEOLOGICAL SOCIETY OF SOUTH AFRICA, 1985). In terms of area, in the valley bottom of Sandrivier (SR site B to E, TB site rs) consolidated alluvial slope deposits are most important. These have been altered, which consequently resulted in soil horizons. Nevertheless, lithological discontinuities can clearly be observed. The alteration of the parent material of the soils along the drainage lines is weaker. Consequently, the stratification of the alluvial material is more prominent. At steeper slopes of the hills at the northern border of the Sandrivier research area the soils are very shallow.



Picture 19: After a rain event of about 30 mm within two days (26/27.March 1998) we had the chance to measure infiltration rates and wetting depths in the "Sandrivier" study area

The alluvial slope deposits of the Sandrivier area consist of different materials. Shale material, which forms the surface about 500m upwards in northern direction seems to be a minor part of the soil bodies of SR sites B to E and dl. At Tierberg boulders of sandstones and tillite indicate that the material was transported over distances in the range of km (compare chapter 3). The analysis of the nine profiles in the three study areas (see chapter 4.2) revealed distinct differences in texture, reaching from loamy sand to sandy clay (see Fig. 4.4), depending on parent material and weathering. The stone content varied widely.

Table 4.2: Geology and geomorphology of the investigated sites

Site	Geology	m a.s.l	Inclination	Aspect
SR site B	consolidated alluvial slope deposits	~ 680	~ 2 %	south-southwest
SR site C	consolidated alluvial slope deposits	~ 680	~ 2 %	south-southwest
SR site D	consolidated alluvial slope deposits	~ 680	~ 2 %	south-southwest
SR site E	consolidated alluvial slope deposits	~ 680	~ 2 %	south-southwest
SR site sh	Permian shale of Ecca Group	~ 695	~15 %	south
SR site dl	unconsolidated alluvial valley deposits	~ 680	~ 2 %	south
TB site rs	consolidated alluvial slope deposits	~ 750	~ 2 %	south
TB site dl	unconsolidated alluvial valley deposits	~ 750	~ 2 %	south
Pb	boulders of tertiary terrace sediments	~ 710	~ 1 %	--

General features of the soils are ochric epipedons, often calcaric materials or calcic horizons, weak developed cambic B-horizons and often enrichment of salts (saline phase). Tierberg soils contain less calcaric material than Sandrivier soils, "SR site sh" is free of carbonates. All investigated soils contain remarkable contents of salts which increases mostly with depth. Near the waterpoint the highest contents of salts are within surface crusts (Fig. 4.4). In the investigated soils the diagnostic limit for a salic horizon is reached, but not the limit for Solonchaks.

Based on the diagnostic horizons and properties described above, the soils can be classified as indicated in Tab. 4.3.

4.4.2 Soil Forming Processes

Changes from rock (and litter) to soil are characterised by development of soil horizons caused by transformation processes, like weathering or mineral formation and decomposition or enrichment of organic material, carbonates and salts and formation of particles to aggregates. In addition transport processes are important factors with water, wind and gravity as acting forces.

A general feature of all soils are signs of denudation due to the enrichment of rock fragments at the surface. This effect is most prominent at the Tertiary plateau (rudic phase) and easy to observe also at the Tierberg research station with fragments up to dm in diameter. At the Sandrivier area the denudation is less pronounced, but rock fragments of some cm in diameter can also be observed (with different coverage) as well as some washes. On the other side, regularly at all sites an accumulation of wind blown sandy material together with litter can be observed below bushes. This sandy cover has a thickness in big variability from some mm to more than 1 dm. Also a common feature of all soils is a weak surface crust with a thickness of mm to cm.

Generally, the investigated soils were quite young. Due to the strong erosion, which transported and transports mixed material from upper layers from one locality to another, soil forming processes permanently start anew.

4.4.2.1 Physical weathering

At the studied sites physical rock fragmentation is of minor importance since (with the exception of SR site sh) the soils have been developed from clastic materials.

4.4.2.2 Decarbonatisation, carbonatisation

As we do not exactly know the nature of the sedimentary original parent material, it is difficult to estimate the recent dynamic of carbonates. Generally the soils are very different in contents of carbonates (see Fig. 4.4), which speaks for very different parent materials and/or different age of soils. Soil types with carbonate decreasing (SR site B, TB site dl) and increasing (SR site D, E, dl, Pb) with depth do occur as well as soils without carbonates (SR site C and sh). Calcic horizons after FAO-UNESCO (1994), we found in SR site dl and in Pb. Nevertheless, an accumulation of carbonates in subsoils speaks for dissolution in topsoils and precipitation in the subsoils. Aeolic transported material may also contain carbonates and could be an additional source, especially for topsoils. In all profiles a pH-value of > 7 could be measured. This indicates generally that leaching of basic cations (Ca, Mg, Na) is limited. Additionally the salt containing soils show clearly, that under the recent climatic conditions the leaching of dissoluted materials is very low. The calcic horizon near the surface of Pb may be a relictic feature from a time when the now isolated highplan was formerly connected to the Oukloofberge and Pb in lower slope position. In any case we can conclude that in the case of the presence of calcium carbonate within the landscape, carbonatisation of soils does still occur nowadays.

Table 4.3a: Soil data measured

Site	Horizon	Depth in cm	pH $CaCl_2$	Electrical Conductivity in mS/cm $EC_{1:2.5}$	$EC_{Sat. Extr.}$ 1)	Bulk density Range in cm	kg/l
SR site B	**Chromic Cambisol** salic phase; young, not very much weathered, reddish-brown coloured type of soil.						
	Ah	0-15	9.7	1.01	7.1	8-12	1.65
	BA	-30	10.0	0.55	4.3		
	2Bwb	-50	9.9	0.42	3.0		
	Bw	-100	8.5	0.91	5.6	51-57	1.54
						77-83	1.66
		-125	8.2	0.70			
SR site C	**Chromic Cambisol** salic phase; see site B.						
	plant hill						1.37
	Ah	0-10	8.3	0.7	4.4	4-8	1.56
	Bwt1	-30	7.6	1.0	6.2	16-20	1.79
	Bwt2	-60	7.1	1.5	9.4	46-50	1.65
	Bw	-100	7.6	1.7	10.6		
SR site D	**Calcaric Cambisol** salic phase; young, not very much weathered soil type with calcaric material.						
	Ah	0-5	8.2	0.25	1.8	1-5	1.61
	Bw1	-30	8.8	0.39	2.4	26-30	1.57
	Bw2	-60	8.4	0.56	3.5		
	Cw	-115	8.0	1.53	9.6		
SR site E	**Chromic Cambisol** salic phase; see site B.						
	M	+18-0	8.8			+13-+9	1.48
	Ah	-25	8.8	0.63	4.5	2-6	1.60
	Bw	-55	9.3	0.52	3.7		
	Bwk	>55	8.4	0.57	3.6		
SR site dl	**Fluvi-Eutric Cambisol**; young, not very much weathered type of soil, alluvial material.						
	Ah	0-25	9.7	0.53	3.8	8-13	1.62
	BA	-45	8.9	0.53	3.8	26-30	1.51
	2 Ah	60	8.5	0.40	2.6	50-54	1.36
	3 Bw	-75	8.5	0.90	5.6	72-76	1.80
	4 Bw	-110	7.8	|			
	5 Bwk	-130	7.9	2.02	12.6		
	6 Bwt	-145	7.8	|		136-140	1.59
	7 Bk	>145	8.4	0.4	1.9		
SR site sh	**Lithic Leptosol**; young, not very much weathered, very shallow soil.						
	Ah	0-5	7.5	0.08	0.6		
TB site dl	**Fluvi-Eutric Cambisol**; young, not very much weathered soil type, alluvial material.						
TB site rs	**Chromic Cambisol** salic phase; see SR site B.						
	crust	0-1		0.29			1.5
	Ah	1-4	7.2	0.21	0.9	0-4	1.5
	Bt	-35	7.4	0.21	1.5	12-16	1.7
	Bwt	-60	8.0	1.08	6.5	40-44	1.7
	Bw1	-75	7.8	1.69	10	60-64	1.6
	Bw2	>75	7.8	1.85	11		
Pb	**Haplic Calcisol** (rudic phase); a soil with accumulation of carbonates and high amount of stones and boulders at the surface.						
	Ah	0-5				0-5	1.26
Tap water Prince Albert			7.58	0.09 (pure)			
Bore hole water Sandrivier			7.94	1.29 (pure)			

1) $EC_{Sat. Extr.} \sim EC_{1:2.5}$/watercapacity

Table 4.3b: Soil data measured (Texture, free of lime; data: Jenny RÖßNER)

	horizon	depth	stones	sand			silt			clay	silt	sand
				cS	mS	fS	cU	mU	fU	C	U	S
		cm	%	%	%	%	%	%	%	%	%	%
SR site E	**Chromic Cambisol**											
	M	+18 - 0	1	3	36	43	5	2	2	9	9	82
	Ah	0 - 20	10	8	24	26	7	6	5	25	17	58
	Bw	20 - 40	61	10	19	19	6	4	5	38	15	48
	Bwk	40 - 70	60	36	23	6	3	1	3	29	7	65
SR site dl	**Fluvi-Eutric Cambisol**											
	Ah	0 - 25	12	9	34	31	7	2	6	11	14	75
	BA	25 - 45	19	19	19	29	7	6	0	19	14	67
	2Ah	45 - 60	1	2	3	29	25	7	10	25	41	33
	Bw1	60 - 75	9	12	23	20	3	6	10	27	19	55
	Bw2	75 - 110	54	20	18	13	3	1	4	41	9	50
	Bwk	110 - 130	16	11	14	24	12	4	7	29	22	49
	Bwt	130 - 145	16	13	18	27	11	3	5	22	20	58
	Bk	> 145	9	14	23	25	7	2	6	23	15	62
SR site sh	**Lithic Leptosol**											
	Ah	0 - 5	34	19	20	25	12	6	4	15	21	64
	Rw	5 - 13	33+	71	11	2	1	1	1	13	4	83
TB site rs	**Chromic Cambisol**											
	Ah	0 - 4	13	30	21	12	8	3	2	24	14	62
	Bt	4 - 35	24	25	18	7	5	4	4	38	12	50
	Bt	4 - 35	48	33	9	3	3	3	2	48	8	45
	Bwt	35 - 60	27	47	16	2	2	2	2	30	5	65
	Bw1	60 - 75	25	49	15	2	2	1	2	30	5	66
Pb	**Haplic Calcisol**											
	Ah	0 - 5	14	2	13	27	12	9	11	27	32	41
	Bwk	5 - 22	69	1	15	21	8	8	8	39	24	37
	Ck	> 22	28+	2	9	17	5	4	7	57	16	27

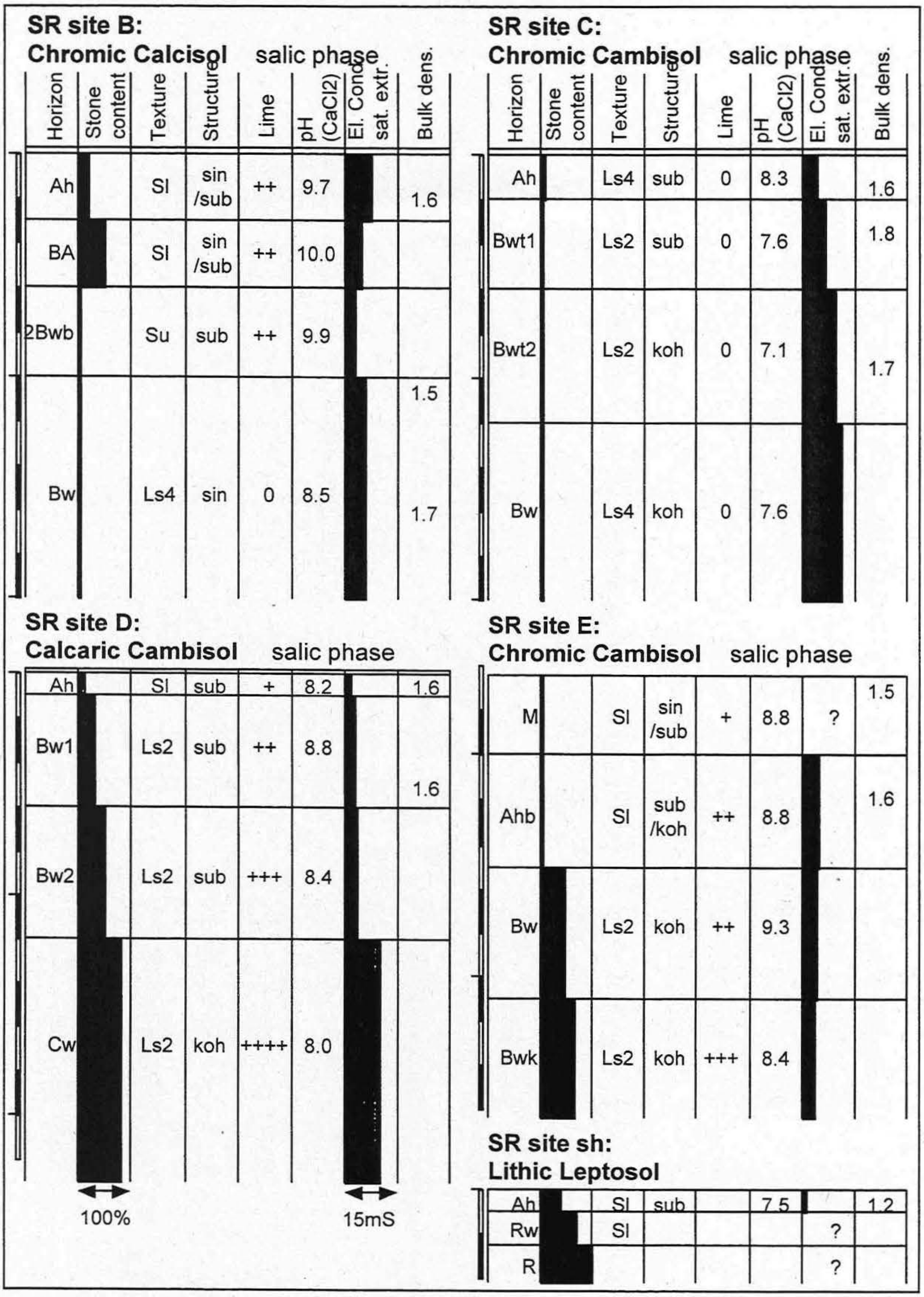


Figure 4.4a: Characteristics of the observed soil profiles (legend see Fig. 4.4b)

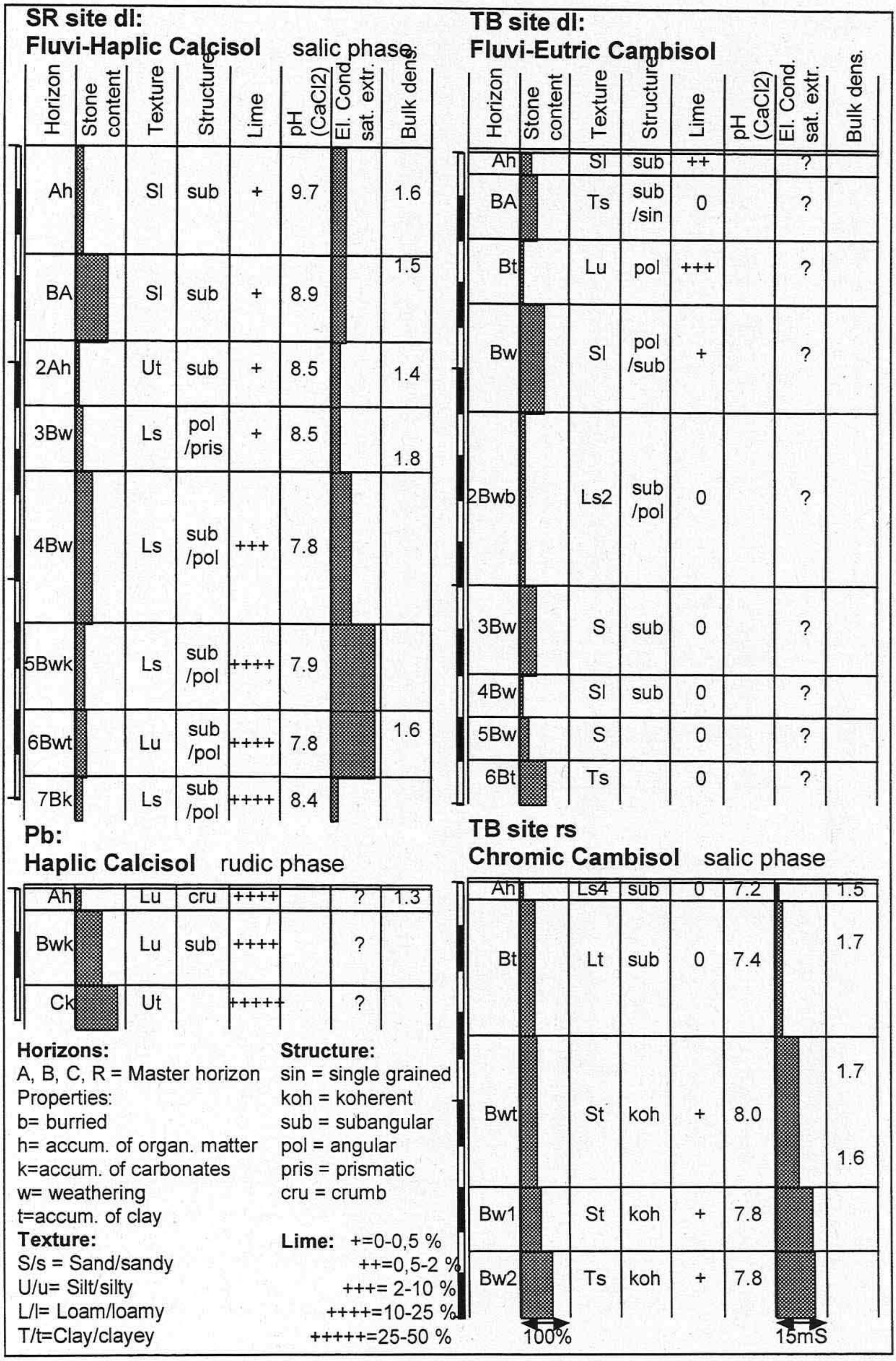


Figure 4.4b: Characteristics of the observed soil profiles

4.4.2.3 Chemical weathering, brownishing, formation of clay

The region in average has 167 mm of precipitation per year, thus chemical weathering could be a soil forming factor. The minerals which arise are distinguishable from the parent material, because they are coloured (iron oxides) or have a finer granular structure, which has been enriched by water and has crystallised.

Partly the level of weathering could be seen by the colour of the soil. Also this feature had a quite strong unsteadiness. In all investigated soils brownish to reddish-brownish colours could be detected, which can be attributed to the formation of brownish and reddish coloured iron oxides (goethite and hematite); in addition there is a connection to clay formation. Due to the fact that in many soils carbonates are present, chemical weathering via hydrolysis should be very low under the present conditions. Therefore the formation of iron oxides and clay minerals seems to be a relictic property of the soils

4.4.2.4 Clay movement

Some soils (SR site C, TB site rs) show in the subsoil weak clay cutans on ped surfaces. In these cases the horizons above are free of carbonates. In both cases the amount of clay cutans is low. The clay contents of the enriched horizon and the horizons above do not fit the texture requirements of an argic horizon after FAO-UNESCO (1994). Nevertheless, this observation is a sign, that under certain conditions soil development towards a Luvisol seems to be possible.

4.4.2.5 Accumulation of organic matter

In arid regions the content of organic material commonly is below 1% due to low biomass (here: ground cover of vegetation less than 25%) and rapid decomposition during moist periods. Our values, measured with field methods, have been in this range in all soils investigated. Therefore, in all soils an ochric epipedon (FAO-UNESCO, 1994) has been classified.

4.4.2.6 Ped formation

The possibility of soil structure formation is biologically based on organic material and biological activity and anorganically based on clay content, kind of minerals, and water dynamics. Since organic material and biological activity in the area is low, ped formation is almost controlled by the texture of the soils. Thus, in the study area a wide range of forms of peds from single grained horizons to polyedric structured horizons occur. The dryness of the region could be a reason for the high bulk density of all nine profiles.

4.4.2.7 Accumulation of salts

The fact, that leaching of dissolved elements is low, has already been explained (see chapter 4.4.2.2). Most soils contain salts (see EC in Fig. 4.4) and fit partly the requirements of a saline phase but not for Solonchaks (real salty soils). Generally, the salt content increases with depth, thus accumulation takes place in the subsoils. Near the waterpoint the accumulation of salts is clearly situated in the topsoil.

4.4.3 Detailed ecological evaluation of the soils

4.4.3.1 Introduction

An ecological evaluation of the soils studied mainly can be done with a comparative approach, which will be performed here, with a focus on the soils‘ suitability for plant growth. Consequently the physical, chemical and biological properties of the soils are assessed with respect to plant requirements like rootability, water storage capacity, nutrient contents, and water as well as nutrient availability. To reach this goal, it is necessary to quantify the properties in a constant and consistent, and thus comparable pattern.

Bulk density is a central criterion for the assessment of rootability, influences the water holding capacity, and is needed to calculate the amount of organic material and nutrients on a whole soil basis. It is closely related to the texture of soil. If the soil consists of finer materials, such as clay, the bulk density is generally low (single peds may have a high ped density). If coarser material prevails, such as sand, the bulk density is generally high. Typically bulk density increases with depth in soils. In the soils examined, we often find loamy material, that means an mixture of clay, silt and sand. A typical characteristic of loamy subsoils is their high density, which causes high penetration resistance.

The actual root distribution also gives a good information on the suitability of soils for plant growth. Quantifications can be made based on depth dependant root density and is measured as number of fine roots per area (e.g. in dm^2, measured on the profiles surface; compare also chapter 5 by DRATH).

Furthermore, the **available water capacity** was estimated, as this might limit plant growth if the storage capacity is smaller than precipitation.

Nutrient status depends on the reserves of nutrients and their availability. The main nutrient reserves in the soils are lime (including calcium), mica and Feldspars which includes potassium, and the organic matter, including nitrogen and phosphorus. The availability is influenced by actual chemical (pH) and biotic (biological activity) soil conditions. Important factors for the estimation of the amount of available nutrients are the cation exchange capacity (CEC) which is positively correlated with clay and organic matter content and pH. Our investigations show moderate to high values of CEC. However, the main limiting factor for plant growth is the low precipitation, thus the plants can not get hold of the nutrients (on nutrients in general compare chapter 6).

The **pH-value** is an indicator for the content of acids in the soil and controls biological activity as well as nutrient supply. In the soils studied there are only high pH-values due to the high contents of lime and salts.

Electrical conductivity is an indicator for salt concentration in the soil. We measured a high conductivity in the first horizons in the areas next to the water point (site A and B). This is most probable due to salt enrichment through the sheeps' excrements as well as from salty water of the bore hole (see Tab. 4.3), which had an enriched salt content due to salt containing rock strata within the aquifer (THERON 1998).

4.4.3.2 Ecological status of the soils studied

"Sandrivier" study area

Site B: *Chromic Cambisol salic phase*

Observation depth was 100 cm. Characteristics are high bulk density, electrical conductivity, and CEC. The high bulk density may be a consequence of the high salt content observed. Salt, especially sodium, destroys soil structure and leads to a high density. Lowest infiltration rates of all profiles were found here (see chapter 4.4.4). Electrical conductivity decreases with depth.

Site C: *Chromic Cambisol salic phase*

Field capacity was moderate to high. Observation depth was limited by very hard and dense loamy material. Therefore a rootability of only 60 cm could be estimated. In this soil there was no calcium carbonate. CEC was medium. Electrical conductivity increases with depth.

Site D: *Calcaric Cambisol salic phase*

This is the site with the lowest value for useable water capacity in comparison to the sites B, C and E. CEC and pH were high. In comparison to the other soils, this one had a much higher rootability because of the rooting depth which reaches more than 130 cm. Electrical conductivity increases with depth.

Site E: *Chromic Cambisol salic phase*

Available water capacity is the highest of all soils examined in the Sandrivier study area. This soil was influenced by termites. Most probably because of their activities, the soil had a higher rootability and an enrichment of organic matter in the upper horizon, which is also shown by the high value of nitrogen in the topsoil. The pH was about 9 in all horizons. Electrical conductivity increases with depth.

Drainage line: *Fluvi-Haplic Calcisol salic phase*

Observation was possible to a depth of 140 cm. Penetration possibilities for the roots are rather good. The rootability was limited to a depth of 120 cm, where a 10 cm thick calcic horizon (enriched and slightly cemented calcium carbonate horizon) formed an unpenetrateable barrier. The enrichment of calcium carbonate often is a limiting factor for the availability of nutrients, especially for phosphorus. The bulk density was very high because of dense loamy material. The average pH trough all horizons has been 7.4. Available field capacity was high, as well as the CEC. In the upper part an electrical conductivity (saturation extract) of about 4 mS is measured, increasing with depth.

Slope of mountain: *Lithic Leptosol*

The Leptosol, which we found on the slope of the mountain chain at the "Sandrivier" study area, had properties quite different from the other sites; mainly a very low soil depth of only 5 cm and therefore a limited space for roots. The weak weatherd rock of the C-horizon also stores some water, which can be used by plants, but here rootability is limited by volume.

"Tierberg" study area

Soils of the Tierberg area are different from the ones in Sandrivier, because of different parent material.

Site on research station: *Chromic Cambisol salic phase*

The useable field capacity was moderate. There was no calcareous material in the first two horizons. Calcium carbonate could only be found in the deeper horizons, with a content ranging from low to moderately high. The pH was around 7. Rooting depth was limited to 75 cm due to very dense material. As the electrical conductivity increases very abrupt with depth, the leaching of salts seems to be hindered by the dense subsoil.

Picture 20:

Soil profile on "Tierberg" research station:
Chromic Cambisol salic phase
(= TB site rs; compare Tab. 4.3 & Fig. 4.4b; March 1998)

Site on drainage line: *Fluvi-eutric Cambisol*

Useable water capacity was low. The rootable depth of 120 cm (effective root space) can be regarded as very good for plant growth. CEC was high. The profile has in the lower part a clear stratification of fluvial transported material (periodic rainfalls). The pH was around 8. The soil also contained loamy material. The calcium carbonate content decreases with an increase in depth. In the second horizon, at a depth of about 30 cm, a higher stone content could be found. That indicates an additional limiting factor for plant growth as it reduces the space for roots. The deeper horizons did not have such a stone ribbon.

"Platberg" study area ("Table mountain" near Prince Albert)

"Table mountain" site: *Haplic Calcisol*

The soils which we can find up on the Table mountain seems to be a remnant of different soil formations since the tertiary time. Thus they have a conspicuous red colour, which is derived from the ironoxide hematite - an indicator for advanced soil forming processes in the past.

Compared to all other soils examined, this soil had completely different forming conditions. The main difference is the location at this tertiary high plain which was connected to the Outkloofberge in former time. Therefore the slope position has changed since the tertiary. We found a huge content of calcium carbonate in all horizons which fits the requirements of a calcic horizon. The pH was above 7. The rooting depth was limited due to weathered carbonate stones (C-horizon) and reached only 22 cm in depth. However, plant coverage was nearly the same like on the other soils (nearly 25%). Low soil depth and high content of coarse rock fragments at the surface indicates that denudation of the area is in an advanced stage.

4.4.4 Water infiltration

The Karoo is a semi desert with low annual precipitation (average: 167mm). All rivers of the region (Sand Rivier and its tributaries) are only episodically filled with water. In the investigated area water shortage is the reason for low biomass production. Due to the arid conditions, in most areas water in the dry season is only available if it is taken from the groundwater, which then is pumped up mostly with wind - and sometimes solar energy - powered pumps (see Picture 7). The groundwater level, measured in the borehole about 40 m in south of the waterpoint of the Sandrivier study area (site A), is around 25m below the surface. Therefore the plant growth of the study site depends exclusively on natural rain. Infiltration rate and storage capacity (available water capacity) are important parameters to describe the water budget of soils. Due to the observation of many washes in the area, it was of interest to know the infiltration capacity, which, in the cases of heavy rains, decides whether the rain infiltrates into the soil or forms surface runoff.

The results of infiltration measurements are presented in Fig. 4.5. In the areas "between" plants the infiltration rate increases from about 300mm/day to nearly 3000/day with increasing distance from the waterpoint. Therefore lower infiltration rates can be assumed around the waterpoint.. This can to a part be explained by a denser surface due to trampling of the sheep. However, the trampling effect must be concentrated to the upper cm of the soils because the measurements of bulk density in the A-horizons (Fig. 4.4) does not fit this assumption. Furthermore, the increasing infiltration rate with distance from the waterpoint (Fig. 4.5) is negatively correlated with the salt contents (Fig. 4.4). High salt contents around the waterpoint may lead to high Na-saturation, reduces stability of peds, enforces the dispersion of particles, and may also result in a compaction of the soil.

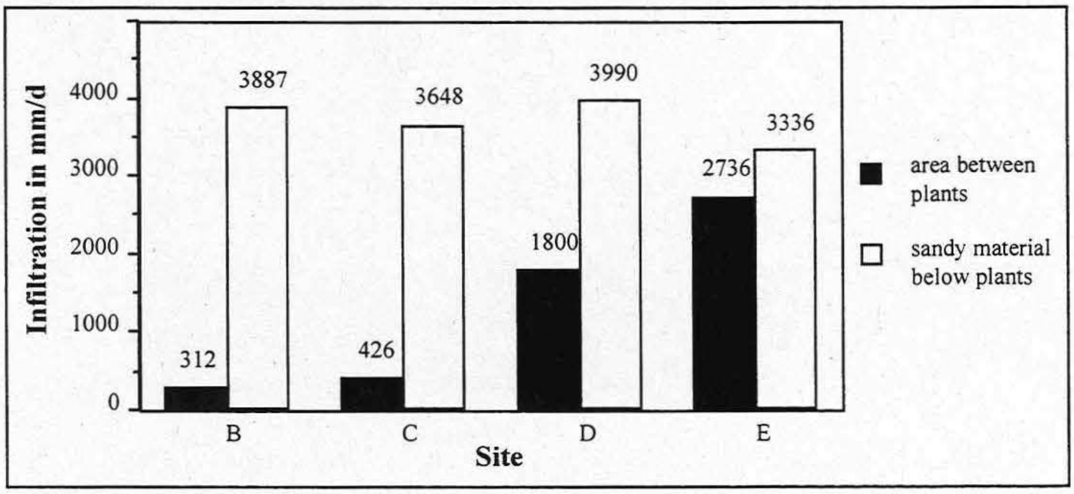


Figure 4.5: Infiltration rates within the Sandrivier study area

The infiltration rate in the sandy material below plants is more than 3300 mm/day in all sites. The higher root densities below plants loosen the structure and create a dense network of root channels, which are also used by the infiltrating water. Additionally, due to the low bulk density and higher amounts of coarse pores of the sandy surface layer (compared to the soil below the surface layer), water is retained and not subject to immediate runoff. Thus, there is more time available for infiltration.

These results fit into the results of the measurements of the wetting depth after rain of about 30 mm within two days. The wetting depth after the rain event at the "plant hills" and in the areas "between plant-hills" was measured (Tab. 4.3, Fig. 5.6)

Table 4.3: Wetting depth of a 30 mm rain in dry soils of the Sandrivier study area

Distance (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Site B	*Malephora lutea*											*Malephora lutea*				
Surface (cm):	+5	+5	+2	+1	0	0	0	0	+2	+3	+4	+6	+9	+9		
Wetting front (cm):	-32	-33	-31	-26	-23	-21	-19	-17	-15	-20	-23	-27	-29	-30		
Site C	*Pteronia pallens*												*Pteronia pallens*			
Surface (cm):	+8	+5	+3	0	0	0	0	0	0	0	0	0	+2	+7	+7	+7
Wetting front (cm):	-35	-35	-12	-9	-55	-19	-14	-18	-19	-20	-13	-9	-13	-46	-50	-55
Site D	*Drosanthemum* spec.												*Pteronia pallens*			
Surface (cm):	+7	+3	+2	+3	+3	+3	+2	+2	+2	+2	+1	+1	0	+1	+2	+6
Wetting front (cm):	-36	-37	-28	-26	-24	-23	-24	-22	-25	-23	-27	-29	-32	-33	-38	-40
Site E	*Pteronia pallens*											*Ruschia spinosa*				
Surface (cm):	+5	+4	+3	0	0	0	0	0	0	0	+2	+2	+6			
Wetting front (cm):	-44	-44	-39	-31	-27	-24	-16	-26	-22	-21	-34	-37	-37			

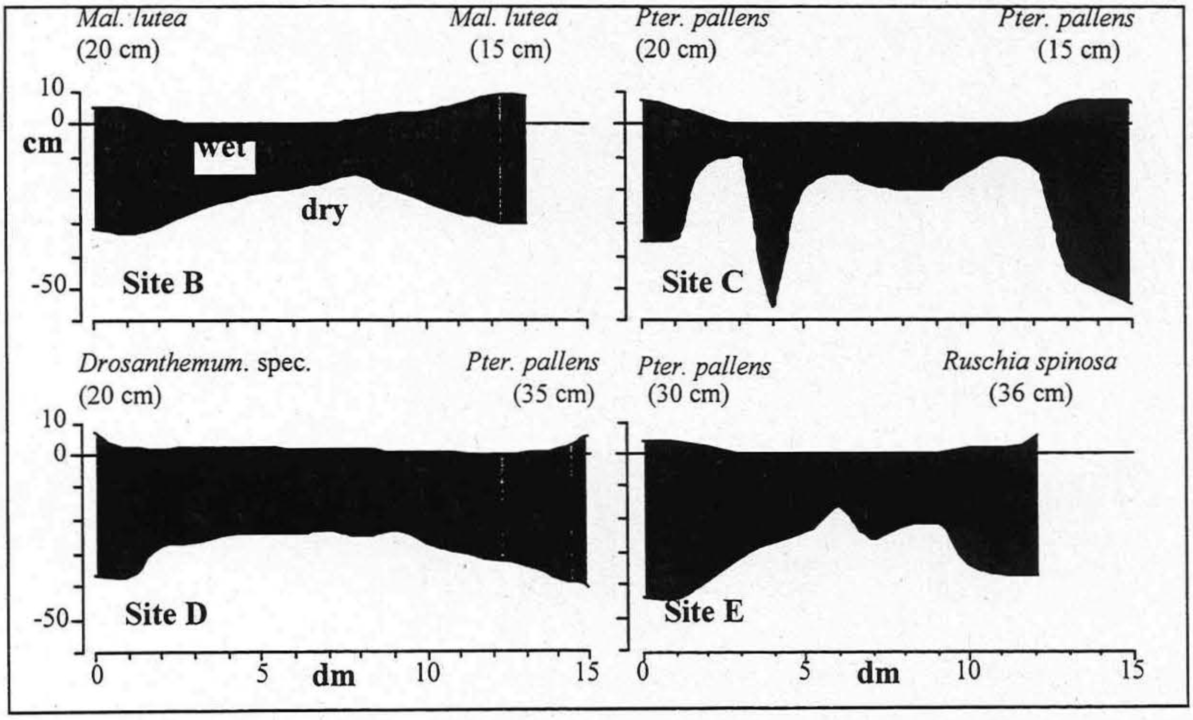


Figure 4.6: Wetting depth of a 30 mm rain in dry soils of the Sandrivier study area

In general, the wetting depth was very irregular between 10 and 55 cm. Regularly however, it could be observed, that water below the plants has infiltrated much deeper into the ground than in the areas between the plants. The surface between plants showed in some cases signs of runoff. In these cases no deeper wetting was observed. The results show very clear, that preferential infiltration occurs below plants and can be explained by higher infiltration rates in the sandy material and - possibly of more importance - a denser root network in the area of plants.

4.5 Conclusions

The soils of "Sandrivier" and "Tierberg" area are very heterogeneous and different, due to different parent material and soil genesis. The parent material in "Tierberg" was mainly sandstone and some tillite and in "Sandrivier" study area mixed material from the hills and the valley (e.g. sandstone and shale). In "Tierberg" we found an Chromic Cambisol with saline phase and in "Sandrivier" study area different Cambisols, all with saline phases as well.

Typical features for all soils are a low weathering state (chemically) and a low humus accumulation. The results of the investigations show a wide range of calcium carbonate concentrations. In the profiles on "Sandrivier" it differs from 0.5 to 25 % in the topsoil and from 0 to 40 % in the subsoil. The topsoils in "Tierberg" profiles have a lower calcium carbonate content than in the subsoils. On all profiles the electrical conductivity was high. Near the water point the electrical conductivity was higher than on other profiles, especially in the upper horizons.

The main stress factors for plant growth are in general

- reduced water availability,
- salt enrichment, and
- dense subsoils.

High bulk densities in the soils and partially high stone contents reduce the rootability. A further stress factor, which is due to land use, is salt enrichment near the waterpoint. The investigation shows lower infiltration rates near the water point than in further distance, caused by trampling effects (due to grazing) and by sodification. With increase of plant cover the infiltration rate increases as well, while soil density decreases. A further positive effect of plant cover is the reduced risk of water and wind erosion. Below plants, sandy material transported by wind is collected together with litter from the plants. Low bulk density and high infiltration rates can thus be observed. The plant stands have preferential infiltration of rainwater and therefore more stored water within the rooting zone (self improvement of plant sites).

A comparison of the study areas ("Sandrivier" and "Tierberg") shows, that plant cover and root density are higher in "Tierberg", which can be explained by the long lasting period without grazing.

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Chapter 5

Root density distributions on selected sites

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5.1 Introduction

The root is a central organ of the plant. Especially the fine root system provides nutrients and water for plant development. Aim of this study has been the analysis of the adaptation of plant root systems to the dry conditions in the Great Karoo.

5.2 Material and methods

The root density was observed at the soil profiles. As counting of roots is very time consuming, only four sites could be examined. A frame of 2x2 cm per cell was used for the determination of the root density by estimating the number of detached roots in classes (0; 2.5; 5; 10; 15 etc.). Then four values were aggregated to one to level out micro scale heterogeneity and assessment errors. Thus, the values per 16 cm^2 grid gave more reliable information about the distribution of the root density in the soil compared to single values per 4 cm^2 grid. For visualising, the root densities have been lumped into fewer classes (of 0; < 10; < 20; < 30; etc. detached roots; compare Figs. 5.1 to 5.4).

Furthermore the change of root densities with increasing soil depth (i.e. along the vertical line) have been analysed. Therefore, every 4 centimetres the total number of detached roots were summarised over a profile width of 56 cm (see Fig. 5.5 left); additionally the total root number was summarised up to the entire depth of the profile (see Fig. 5.5 right). Relative proportions of roots have also been computed, taking the total of 0 to 60 cm in depth as 100% (see Fig. 5.6)

A further aspect investigated was the root distribution along the horizontal line. The results of the estimates of root numbers were summarised up to a depth of 20 cm and a width of 4 cm, as the horizontal root distribution in depths below 20 cm increasingly depends on the bulk density of the soil rather than on the influence of the plant itself. Arithmetic means and standard deviations of these values are also given (see Fig. 5.7).

5.3 Results and discussion

Figures 5.1 to 5.4 show distributions of root densities in the soil profiles. First it becomes obvious that the root densities decrease with increasing depth of the soil. The highest root densities are in the upper soil layer near the surface in a depth of 4 to 20 centimetres. In larger depths the roots follow fissures and cracks in the consolidated soil. This can be seen in Fig.

5.4 of the Tierberg site (Chromic Cambisol = TB site rs; compare chapter 4, especially Tab. 4.3, Fig. 4.4b, and Picture 4.4). Fig. 5.1 shows the profile of site B at Sandrivier (Chromic Cambisol = SR site B; compare chapter 4, especially Tab. 4.3 and Fig. 4.4a). It is obvious how the root densities follow the borders of the soil horizons and bulk densities. There is a strong correlation between the decreasing root densities and the borders of the horizons (compare with Fig. 5.2).

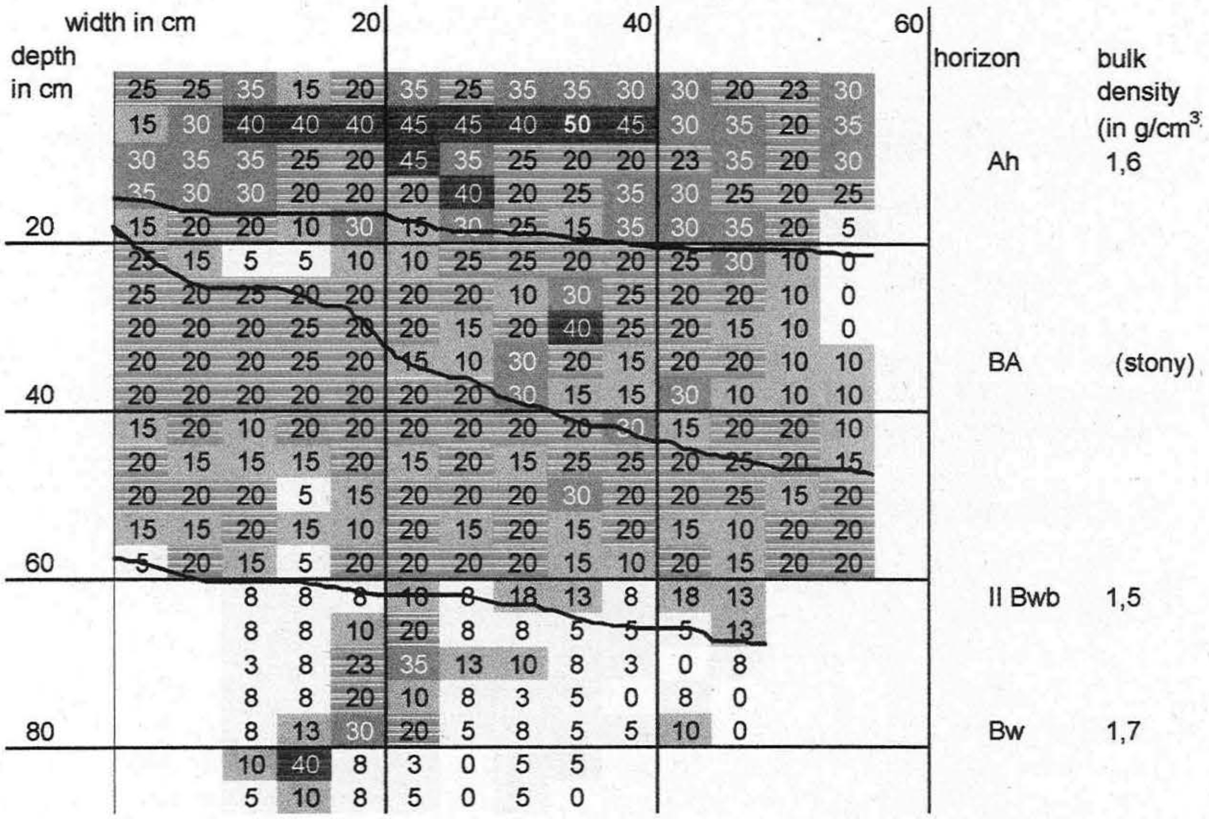


Figure 5.1: Distribution of the root densities of soil profile site B on „Sandrivier“ , (number of detached roots per $16cm^2$) and soil horizons with their borders and bulk densities (soil: Chromic Cambisol = “SR site B”; compare chapter 4, especially Tab. 4.3 and Fig. 4.4a)

The comparison of the 4-cm-summarised vertical root densities of all profiles in Fig. 5.5 (left) gives an overview, how the root density depends upon the soil depth. In Fig. 5.5 (right) the total summarised root densities are plotted up to the total profiles' depths. The results show that the total amount of roots in the profiles decrease with higher distance from the waterpoint, from site B to site E. The relative proportions of the sums can be seen in Fig. 5.6.

Within a parallel botanical study (see chapter 7 by Bauer et al.) a groundcover of only 20 to 30% has been recorded in the field. That means that much uncovered soil surface can be found between (little groups of) plants. The horizontal root distribution (Fig. 5.7) shows that in contradiction to the patchy occurrence of plants on the surface, the root system is more homogeneous. The standard deviation within the upper 20 cm is mostly only 15 to 20% of the mean.

5.4 Conclusions

The following hypotheses can be made, based on the few data gained within this study, to stimulate more detailed research with many more replications as to achieve statistically profound results some time in the future.

- Total amount of roots decreases with increasing distance from waterpoints.
- The higher amount of roots in the subsoil in site B (near the water point) in comparison to the other profiles indicates that the salt concentration is a regulative for the root distribution in the vertical direction. High salt concentrations on the surface force the roots to grow in deeper layers of the soil.
- The aboveground vegetational gaps are not reflected in the root distribution. Roots are mor4 or less evenly distributed even in the uppersoil layers. A hypothesis for the explanation of this would be that the gaps mark the area, which an individual plant needs to acquire enough nutrients and water.

Picture 21: Explaining the root distribution analysis during a joint field day of German and Cape Town students ("Sandrivier", March 1998)

width in cm / depth in cm					20					40					60		
	15	18	13	10	10	28	13	20	30	18	25	15	15	18	13	25	25
	8	23	25	20	13	28	15	28	30	35	23	25	15	8	13	30	25
	18	25	13	15	15	13	15	18	23	18	15	20	23	23	13	13	15
	18	30	20	23	13	15	13	13	15	18	15	15	20	13	15	13	15
20	15	13	13	13	10	10	15	13	15	13	35	28	13	13	15	13	15
	13	13	13	13	15	15	13	13	15	18	13	13	13	13	18	13	13
	13	13	13	13	13	13	15	13	13	13	15	15	15	13	13	8	13
	20	15	13	15	13	15	13	8	13	8	20	13	13	13	13	5	13
	15	13	13	15	15	0	8	3	5	5	35	28	13	13	13	8	13
40	18	15	8	13	13	3	5	10	15	18	25	18	13	13	13	13	10
	15	15	5	5	10	13	3	8	5	15	15	3	8	20	13	13	8
	13	18	5	3	3	3	8	5	5	10	30	13	8	5	5	13	5
	0	5	8	5	8	8	8	8	5	18	18	5	8	5	5	8	5
	0	5	13	3	8	28	10	0	10	13	15	18	18	13	5	5	3
60	5	3	3	3	13	28	8	0	8	5	3	0	0	8	13	8	3
	3	0	5	5	0	13	13	3	0	0	0	0	0	13	13	8	8
	3	3	3	0	10	10	18	3	3	3	0	3	0	0	3	0	5
	13	3	8	3	3	10	8	8	10	8	5	3	3	0	3	0	3
	5	5	5	3	0	13	3	8	15	8	3	3	0	3	8	0	3
80	8	5	3	3	0	3	0	10	15	10	8	8	3	3	0	5	3
	5	13	13	5	13	3	10	13	13	13	5	0	0	5	3	13	8
	3	5	5	3	3	13	13	8	15	8	8	0	0	0	0	10	10

Figure 5.2: Distribution of the root densities of soil profile site D on „Sandrivier"
(number of detached roots per $16cm^2$)
(soil: Calcaric Cambisol = "SR site D"; compare chapter 4, especially Tab. 4.3 and Fig. 4.4a)

width in cm / depth in cm					20					40						60	
	13	13	13	13	13	13	13	13	13	13	13	13	13	15			
	13	15	13	18	15	13	13	13	15	13	15	13	15	13			
	13	18	13	15	15	13	15	15	15	15	18	18	23	8	13	18	13
	15	33	15	28	33	15	20	25	35	23	23	13	15	15	8	13	10
20	20	15	8	15	28	15	20	30	50	23	15	8	8	15	15	3	3
	13	13	8	8	8	5	8	13	13	15	13	13	18	8	5	20	15
	3	3	3	8	8	3	8	13	13	10	15	15	15	18	8	25	15
	10	0	8	3	3	13	10	13	15	10	13	8	15	15	8	20	3
	13	10	8	3	8	15	15	13	15	15	13	13	13	13	13	13	0
40	5	5	8	13	10	18	15	13	15	13	5	10	8	13	15	3	5
	5	5	5	8	10	13	15	15	8	8	0	8	8	8	13	8	10
	0	13	3	13	3	5	5	5	0	5	5	8	8	18	13	5	0
	5	5	5	8	13	8	5	3	3	0	5	3	8	18	8	5	0
	0	0	3	10	8	5	5	13	5	13	3	8	5	5	0	5	0
60	0	3	3	0	13	8	3	8	8	0	5	8	8	13	13	3	0
		8	5	13	5	5	0	3	0	8	8	8	3	5	3		
			13	13	8	0	0	3	0	13	0	3	5	5			

Figure 5.3: Distribution of the root densities of soil profile site E on „Sandrivier"
(number of detached roots per $16cm^2$)
(soil: Chromic Cambisol = "SR site E"; compare chapter 4, especially Tab. 4.3 and Fig. 4.4a)

depth in cm \ width in cm					20					40					60					80					100
	35	25	15	30	20	30	40	38	38	25	13	20	20	15	13	35	30	18	15	23	18	18	35	18	30
	23	35	45	30	25	35	25	45	50	50	30	30	23	15	25	30	50	40	35	30	25	25	40	30	40
	38	35	35	40	25	45	45	28	40	50	35	15	23	30	23	30	40	50	60	45	25	35	55	40	40
	20	40	30	45	30	45	30	25	30	40	30	35	20	20	25	35	40	30	25	30	25	40	50	50	25
20	15	40	30	45	40	35	40	20	30	25	25	28	25	15	18	23	40	30	20	25	20	25	30	35	25
	23	25	25	25	18	40	45	25	13	30	25	30	20	18	15	15	40	13	5	18	25	25	30	35	30
	13	30	40	25	20	18	25	13	13	30	13	18	25	18	25	25	30	28	10	13	20	18	35	30	20
	20	35	40	23	23	20	10	5	20	13	15	13	18	20	13	15	23	18	5	18	8	30	23	23	18
	33	40	30	25	18	30	30	15	15	35	30	33	20	25	13	13	10	5	10	13	8	28	25	20	23
40	25	20	25	23	25	25	23	35	28	25	3	13	15	15	13	10	15	5	3	8	13	40	35	18	10
			18	20	30	28	8	5	3	3	3	20	13	23	23	23	3	3	3	5	35	35			
			15	18	20	10	15	0	0	0	8	40	30	18	30	10	0	0	0	0	3	23			
			18	28	13	10	23	10	0	0	15	40	30	40	35	0	0	0	0	0	0	5			
			30	20	0	30	33	5	0	0	15	20	35	45	3	0	0	0	0	0	0	0			
60			10	0	0	8	3	0	0	0	0	20	40	30	0	0	0	0	0	0	0	0			
			0	0	0	0	0	0	0	0	0	3	35	33	0	0	0	0	0	0	0	0			
			0	0	0	0	0	0	0	0	0	10	35	3	0	0	0	0	0	0	0	0			
			0	0	0	0	0	0	0	0	3	10	15	0	0	0	0	0	0	0	0	0			
			0	0	0	0	0	0	0	0	18	25	30	5	0	0	0	0	0	0	0	0			
80			0	0	0	0	0	0	0	0	13	18	40	8	0	0	0	0	0	0	0	0			

Figure 5.4: Distribution of the root densities of soil profile site rs on "Tierberg" (number of detached roots per $16 cm^2$) (soil: Chromic Cambisol = "TB site rs"; compare chapter 4, especially Tab. 4.3 and Fig. 4.4b)

depth in cm	site B	site D	site E	Tierberg
	383	265	184	301
	510	308	197	458
	398	239	214	501
	375	216	308	425
20	305	221	270	349
	225	198	156	292
	265	185	135	286
	270	205	136	229
	255	174	167	258
40	260	182	151	206
	260	139	116	195
	265	116	91	162
	270	114	89	165
	230	149	83	118
60	225	100	80	90
		76		71
		58		48
		67		28
		70		78
80		71		79
		104		
		91		

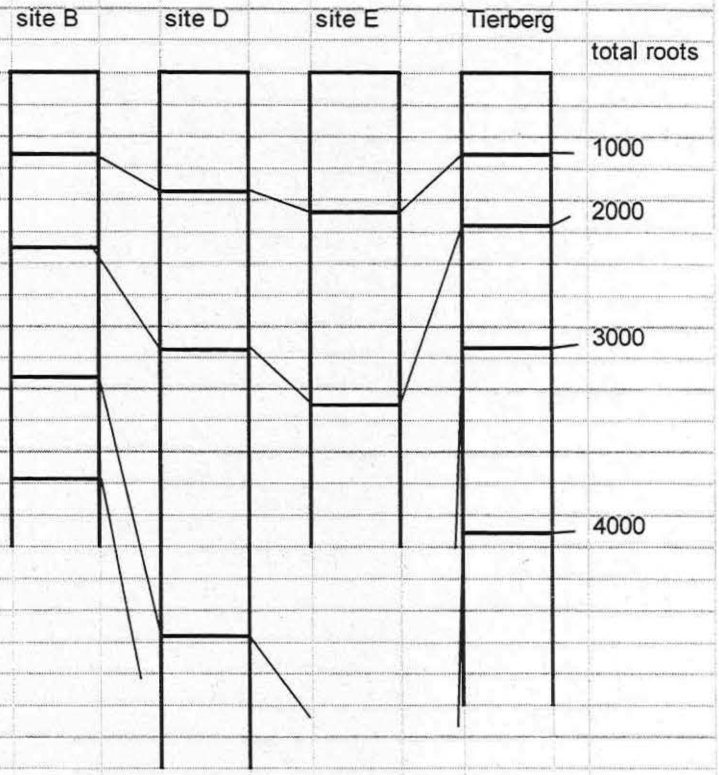


Figure 5.5: Vertical distribution of the root densities
left: summarized root densities in layers of 4cm and over a total width of 56cm)
right: root densities summarized up to the total depth

depth in cm	site B	site D	site E	Tierberg
	8,5	9,5	7,7	7,5
	11,3	11,1	8,3	11,4
	8,9	8,6	9,0	12,4
	8,3	7,8	13,0	10,5
20	6,8	7,9	11,4	8,6
	5,0	7,1	6,6	7,2
	5,9	6,7	5,7	7,1
	6,0	6,3	5,7	5,7
	5,7	6,3	7,0	6,4
40	5,8	6,5	6,4	5,1
	5,8	5,0	4,9	4,8
	5,9	4,2	3,8	4,0
	6,0	4,1	3,7	4,1
	5,1	5,4	3,5	2,9
60	5,0	3,6	3,4	2,2

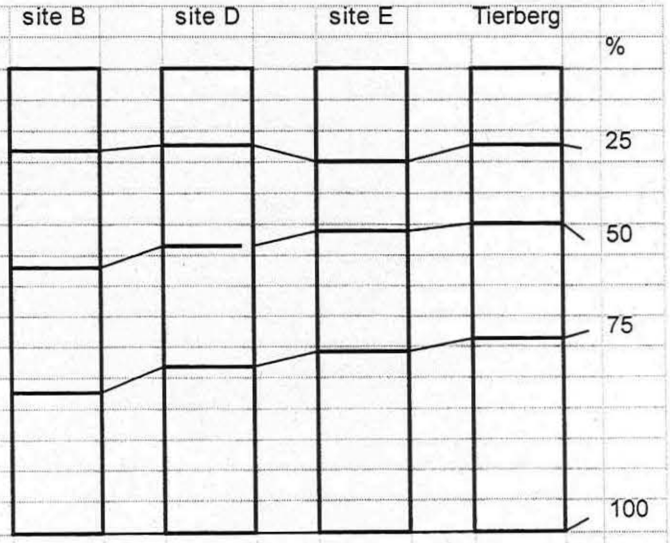
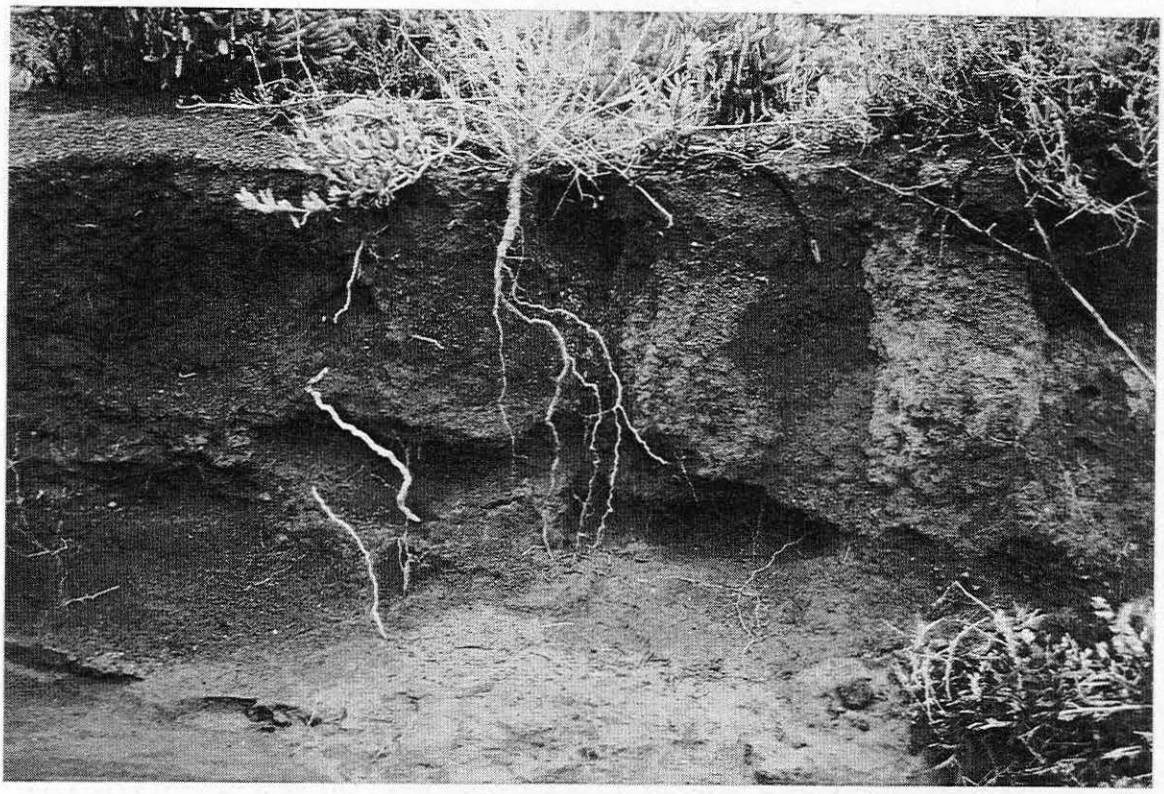


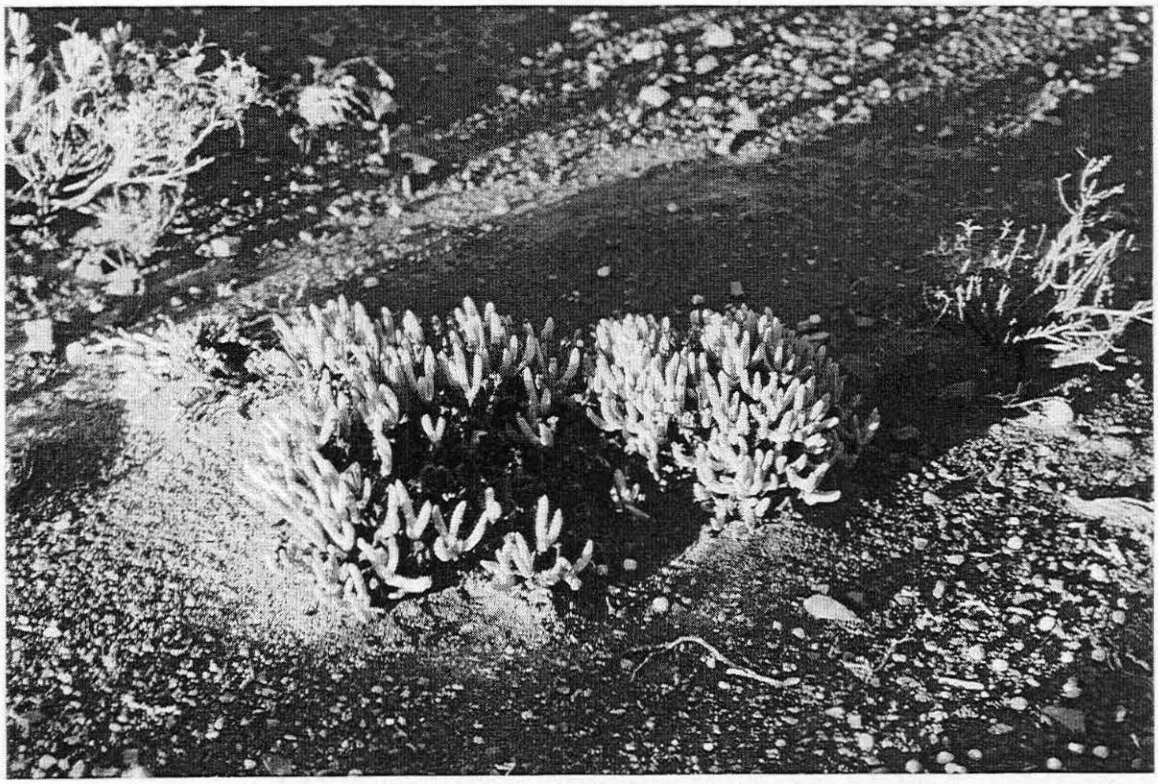
Figure 5.6: Relative proportions of vertical distribution of the root densities
left: summarized root densities in 4 cm layers, over a total width of 56cm (depth of 60 cm = 100%)
right: root densities summarized up to a depth of 60 cm (= 100%)

	width in cm			20					40					60					80					100			
profile																											
SR site B								*Dros. mont.*			*Augea capensis*						*Drosanthemum montaguense*									x=	141
																										s=	21
						120	140	160	110	130	160	175	145	145	165	143	150	103	125							s%=	15
SR site D										*Augea capensis*								*Pteronia pallens*								x=	89
																										s=	16
					74	109	84	81	61	94	71	92	113	102	113	103	86	75	69	94	95					s%=	18
SR site E										*Augea capensis*				*Pteronia pallens*												x=	84
																										s=	18
						74	94	62	89	104	69	81	96	128	87	84	65	74	66							s%=	21
TB site rs									*Augea capensis*														*Ruschia spinosa*			x=	156
																										s=	31
131	175	155	190	140	190	180	156	188	190	133	128	111	95	104	153	200	168	155	153	113	143	210	173	160		s%=	20

Figure 5.7: Distribution of root densities along the horizontal line (summarised roots up to a depth of 20cm and a width of 4cm)



Picture 22: Roots along a wash ("Sandrivier", March 1998)



Picture 23: Contracted vegetation and heaps formed around plants (compare chapter 6.1; March 1998)

Chapter 6

Nutrients in Soil and Vegetation around an artificial Water hole in the Karoo, South Africa

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6.1 Introduction

It is known from the study area Tierberg in the Karoo of South Africa, that grazing of sheep can result in change of vegetation cover and composition (DEAN et al, 1995b; DEAN et al., 1995b; MILTON, 1995a; compare chapter 7 of BAUER et al.). Whether a similar piosphere gradient can be observed for soil properties has not yet been investigated for this specific area. However, several studies from Botswana (TOLSMA et al., 1987; PERKINS & THOMAS, 1993) for sheep, goat and cattle ranging systems in semi-arid areas (400-500 mm rainfall) have shown that the higher frequency of animals around a water hole can have an impact on soil properties. Gradients were found for the amount of macronutrients (N, P, K, Ca, Mg) as well as for some micronutrients (Fe, Na, Mn, Zn). Likewise the content of organic matter and the soil pH decreased with increasing distance from the artificial water holes.

The change of soil nutrient distribution around a water hole in these studies was also reflected in the nutritional status of the plants and thus the amount and quality of fodder available for the animals along the piosphere gradient. TOLSMA et al. (1997) reported increased uptake of N, P, K, Na and Fe for plants growing close to the water hole.

The idea of the present study was to test the findings from Botswana for the Karoo sheep grazing system. To be able to interpret any differences in nutrient content between several sites as a gradient prior information on the heterogeneity of the parameters is required.

In contracted vegetation like the one present in the Karoo different sources of variability for soil chemical parameters can be found. The contracted vegetation results in patches of soil which are not covered by plants while the ones covered with plants are often elevated. These heaps formed around plants are regarded as "islands of fertility" by some authors (GUTIERREZ et al., 1993; SCHLESINGER et al., 1996). Whether the heaps really are more fertile patches than the surrounding probably depends on their origin. Shrubs like *Pteronia pallens* form a dense canopy and might thus function as a trap for wind blown seeds and dust (MILTON & DEAN, 1996). In addition, due to their long life span, throughout the years litter can accumulate underneath them and serve as carbon source for microorganisms, which in turn initiates nutrient cycling (EVENARI, 1985). It is also possible that the micro climate underneath the shrubs is more suitable for microorganisms than in the bare soil.

The heap formation could also be simply a result of erosion. Plants with an extensive root system, especially in the topsoil can hinder soil erosion after heavy rains. In such a case the heaps would not be a site of accumulation but a site where loss of material was avoided. That water erosion does occur in the area was obvious after the thunder storm encountered during the field study. If wind erosion would be the dominant process dust would accumulate in the plants as mentioned above and thus contribute to heap formation. Accumulation of fine or coarse particles at the surface of the heaps could indicate whether fluvial or alluvial erosion is the dominant process in the Karoo ecosystem.

For some plants specific physiological parameters could also affect the formation of heaps below them. For example halophytes, which accumulate Na in their leaves and thus in the litter could enrich the soil surface underneath them with Na, which would result in clay dispersal and thus favour erosion.

A second source of heterogeneity in the Karoo ecosystem is the phenomenon of heuweltjie. MILTON (1995) held the assumption that heuweltjies are overly nests of the smaller harvester termite *Microhodotermes viator* (LATREILLE). Heuweltjies are low mounds, which appear as lighter patches with varying size. MILTON et al. (1992) found that they have an average diameter of 13 m and occur with a frequency of about two mounds per hectare on the study area Tierberg. There is some evidence that heuweltjies are sites of higher $CaCO_3$ content and are enriched with organic matter and nutrients (MILTON et al., 1992). An aerial picture from a hill near the study area Sandrivier (Picture 6 in chapter 1) revealed the presence of heuweltjies within the study area. Thus this special feature was included in the investigations to determine to which extent the heuweltjies differ from the surrounding soil for the parameters measured.

For a sound interpretation of soil chemical data, especially of depth functions, information on the history of the soil, geological origin, soil forming processes are required. Such data were collected by the soil group (see chapter 4 by RÖßNER et al.). By analysing the different horizons from the soil profiles of this group some conclusions on the depth of a possible piosphere gradient could be derived. Due to the framework of investigations (two week field study) the soil chemical parameters which could be measured were limited. Soil N was not measured although it is very often the limiting factor for plant growth and animal activity could influence soil N distribution. Measurement of N would have required NH_4- and NO_3-test as well as some urease pre-treatment. In addition it was likely that the field test-methods available would have been not sensible enough to measure the expected N_{min} concentrations.

P was measured as the extraction method for plant available P could be adapted to the expected values beforehand. P is often limiting for plant growth in arid areas. It originates from the slow weathering of primary minerals, mostly apatite. The mobility of P in soil is in general very low. In acid soils P is immobilised by the formation of Fe- or Al-phosphates and through Al- and Fe-oxides and hydroxides, in alkaline soils the formation of Ca-phosphates decreases the availability of P.

K was chosen as the second element for analysis as it could be measured with the same extraction method as P and it was known from other studies that a piosphere gradient could be expected. In addition K was suitable for analysis in plant press sap as the majority of K in plants is stored in the vacuoles and is thus released by destroying the plant cells.

Electrical conductivity was measured as a general indicator for salt accumulation which can be expected to occur in arid climates especially in relation to water holes. Soil pH was determined as it is important to characterise soil chemical properties (CEC, chemical reactions) and as the field tests used were only suited for a certain pH range.

6.2 Materials and Methods

6.2.1 Study area

The study areas Sandrivier and Tierberg are situated on the southern edge of the Great Karoo (33 ° 10' S, 22 ° 17' E) inland and 20 km north of the Swartberg mountain range, South Africa.

Sandrivier study area is located on a plain between some little hill ranges, about 18 km east of Prince Albert. Tierberg Karoo Research Centre (100 ha) lies about 26 km east of Prince Albert at 800 m above sea level in the 5 km wide and 80 km long valley of the Sandrivier, which flows east along a syncline in folded Ecca shale beds for approximately 60 km before joining the Gamka river. Tierberg was selected as a reference site for its flatness and homogeneity of vegetation in comparison to the grazed area Sandrivier. Tierberg is drained by six small washes, which join a single drainage line running SSW, but the surface water is present in the area only during heavy rainstorms, when run-off is rapid and muddy rivers incise the washes and drainage line.

The climate around Prince Albert is arid throughout the year. The average rainfall amount is 167 mm per year. Mostly in the summer there are brief cloudbursts which result in rapid run-off. The study area falls within this region with a mean annual temperature of 17,5 °C (MILTON et al., 1992).

The general plant community is characterised by evergreen and deciduous succulents (*Ruschia* spp., *Malephora lutea, Augea capensis, Brownanthus ciliatus* etc.) and by taller non-succulent shrubs such as *Pteronia* spp., *Galenia fruticosa* and *Osteospermum sinuatum*. Underneath the shrubs there are few annual forbs and between the single shrubs interspaces with no vegetation.

A general map of the study areas Sandrivier and Tierberg and the position of the examination sites A to E in Sandrivier is given in chapter 1 of this report.

6.2.2 Sampling

6.2.2.1 Shrub gradient

At Sandrivier, four different species (*Pteronia pallens, Malephora lutea, Brownanthus ciliatus, Ruschia spinosa*) were chosen to allow comparison of various plant shapes in respect to their soil capture and hold function. The sample sites were located in a distance of 150 m and 800 m from the water hole. At each sample site three transects were sampled for each species. One transect comprised three soil samples, which were taken with a little cylinder corer from the first five soil centimetres underneath two single shrubs (one sample under each shrub) and in the interspace between the two shrubs. Furthermore the distance between the shrubs and the diameter of each shrub were measured and the height of the little heaps underneath the shrubs was recorded.

A 15 m long transect was chosen for the sampling at the reference site Tierberg. Similar to the sampling at Sandrivier, soil samples from 0-5 cm were collected underneath the shrubs and in the interspaces between the shrubs. Besides the shape of the shrubs was recorded.

For the soil samples, the pH-value, EC and the available nutrient contents of phosphorus and potassium were measured.

6.2.2.2 Heuweltjie

At the study area Sandrivier one heuweltjie was chosen in 800 m distance from the water hole. Soil samples from different depths were taken with an auger along a small transect from the centre to the edge of the heuweltjies in 0, 1, 6 and 12 m distance to the centre. The Calcium carbonate ($CaCO_3$) content was determined in the field with hydrochloric acid drops and results assessed according to "Bodenkundliche Kartieranleitung 4" (ARBEITSGRUPPE BODEN 1994).

An analysis of the pH-value, the EC and the available potassium and phosphorus content of the soil samples was conducted as described below.

6.2.2.3 Profiles

The prepared soil profiles at sites B to E of the Soil group were investigated to determine the depth function of available nutrient content. One soil sample was taken of each horizon for the analysis of the available P and K content, the pH-value and the EC.

6.2.2.4 Topsoil gradient

A topsoil gradient was investigated in Sandrivier on site C, 150 m from the water hole. Samples were collected in a very fine scale, 0-1 cm, 1-3 cm and 3-5 cm depth, to get detailed information about the topsoil. Three soil samples were taken for each depth. They were analysed for pH-value, EC and available phosphorus.

6.2.2.5 Plant press sap gradient

Leaves from two different succulents, *Malephora lutea* and *Augea capensis,* were collected randomly on every examination site of Sandrivier. These succulent species were chosen because of their high water content and as they occurred at all sites. Always the second leave pair from the tip of a branch was taken to ensure that leaves of similar physiological age were combined to one bulk sample.

The leaves were pressed for measuring the potassium content and the EC in the plant press sap. By measuring EC only the charged solutes in the press sap could be detected. No information on other solutes (sugars), contributing to osmotic potential was obtained.

6.2.2.6 Piosphere gradient

For the examination of the piosphere gradient in Sandrivier (0-800 m), soil samples from the A-horizons of the soil profiles (see chapter 4) and the samples from the shrub gradients were evaluated together. This was possible for site B to E.

On site A, structures were found, which consisted of little fluffy heaps with a crust on the top and interspaces with the compactness of the surrounding area. Soil samples were taken from two crusts, the soil below the crusts and from the interspace (mixed sample).

All soil samples were analysed for pH-value, EC and available P and K contents.

6.2.3 Analysis

6.2.3.1 Preparation

The plant leaves were pressed in a mortar to extract plant press sap. Plant press sap was diluted 1:10 with deionised water.

The soil samples were air-dried and sieved <1 mm, as no 2 mm sieve was available. For the pH-value and EC, soil samples were extracted 1:2.5 with potable water (EC 0.2 mS/cm, pH 7.4) by 5 min hand shaking (modified from Schlichting et al.,1995). The available phosphorus and potassium content in the soil was determined after a 1:5 calcium lactate (DL) extraction (modified from VDLUFA 1991). Samples were shaken by hand for 5 min and filtered (Schleich & Schüller, 512 ½).

6.2.3.2 pH-value

The pH-value was measured with an electrode (WTW pH-meter). In the present study pH measurements were conducted to secure that quick-test-methods could be applied without interference with high H^+- or OH^--concentrations.

6.2.3.3 Electrical conductivity (EC)

EC is a measurement for the amount of charged particles, irrespective of their chemical origin. The EC of a solution depends on the concentration, the degree of dissolution and the valence of the ions formed. It was measured with an electrode (Hanna conductivity-meter) in the extracts and dilutions. The measurement were given in [mS/cm].

6.2.3.4 Quick-test-methods

Phosphorus can be detected with the selected quick-test-method in the form of PO_4^{3-} and potassium in the form of K^+. The precision, which can be achieved, is not as high as the one with standard methods in the laboratory but as transport is easy and results are available quickly, they were used to show big differences in the concentrations. The system used was Reflectoquant® from MERCK, consisting of the apparatus RQflex® and the Reflectoquant®-strips. The system is based on reflectometrie (Re-emissionsphotometrie). The sensor is able to detect the difference in the intensity of emitted and reflected signals. The difference corresponds to the concentration of the respective chemical in the sample solution. The system was developed for the measurement of concentrations in soil extracts, sewage water and fertiliser.

Phosphate-test

PO_4^{3-}-ions form molybdate-ortho-phosphoric acid through the addition of molybdate-ions. After reduction a blue complex is formed which can be detected by reflectometry. The measurement range was 5 - 120 mg/l PO_4^{3-}. (For comparison: The threshold value for phosphate in drinking water in Germany is 6.7 mg/l (TVO 5.12.1990).) Distilled water was used to check the function of the system.

Potassium-test

K^+-ions form an orange complex with dipicrylamin which can be detected by reflectometry. The measurement range was 0.25 - 1.20 g/l K^+. This range covers only the highest values which could be expected to occur in the field. Thus potassium measurements could only be used to detect accumulations but not to show variations in the background values.

6.2.4 Statistics

Where it was possible, mean values and standard deviations were calculated for the evaluation of the results. In the case of K^+ the lowest value which could be detected was 2,5 g/kg. However, as values below the measurement range occurred frequently, these were set to be 1.25 g/kg to allow calculation of mean values, where this was required.

6.3 Results and discussion

The field test methods used for the determination of P and K with the modified DL-extraction gave results which could be reproduced any time and the values were in the same order of magnitude described in other studies conducted in the area (MILTON et al., 1992). The major problem was, that the measuring range for K was very high. As a consequence accurate values were only obtained for sites where K had been accumulated.

The maximum values for the available P (77 mg/kg) and available K (3.8 g/kg) were rather high for systems which are managed without the application of mineral fertiliser. Usually the available phosphorus content lies between 10 and 30 mg/kg, if the soil is not fertilised. For the available potassium values from 40 to 400 mg/kg are found.(BLUME, 1992). A reason for the high values determined in the present study is certainly the use of calcium lactat as an extraction medium. The extraction takes place at a pH of about 4, which is much lower than the pH measured in the field. Especially for P, which is present as Ca-phosphate at pH values > 6.0, the plant available P fraction was overestimated with the selected method. This has to be taken into account when absolute values are discussed.

The results from the different features causing heterogeneity in the soil chemical composition will be presented first as they provide the basic information for the evaluation of any gradient along the piosphere.

For soil pH and EC no difference between samples taken underneath the shrubs and those taken in the interspace could be detected for any of the shrub species (data not shown). Likewise no clear picture could be found for the nutrient distribution (Fig. 6.1 and 6.2). While along most shrub transects no difference could be found between sampling locations neither for P nor for K, some exceptions occurred. K values underneath *Brownanthus ciliatus* were significantly higher than in the interspace. However, the opposite was observed for *Malephora lutea* at 800 m distance but not at 150 m distance.

As could be expected from the results at Sandrivier study site no difference between shrub and interspace was found along the 15 m transect at Tierberg for any parameter (Fig. 6.3). However, at Tierberg site heterogeneity due to unknown factors became obvious along the gradient as there was a distinct difference between the values measured along 0 - 5.5 m and the ones measured for 5.5 - 15 m.

In summary the results obtained for the shrub gradients were not very clear and are difficult to interpret. There are a number of factors which could have influenced the mechanisms of fluvial or alluvial erosion discussed earlier, like size or age or shape of plants. For example *Brownanthus ciliatus* is a mat-forming leaf succulent of lower height (maximum 10 cm), thus this plant could probably hinder soil erosion by directly covering the soil. The parameters measured in the present study, plant diameter, heap height, distance between shrubs (Appendix: Tables A6.3 & A6.4), were not sufficient to explain the results. As there are to many parameters which could have an influence on the origin, age and composition of the heap found underneath a shrub, it is likely that a higher number of samples is needed to test the hypothesis of nutrient enrichment. It could be helpful for further investigations to put more emphasise not only on plant size and species but also on the topography of the habitat (distances to drainage lines) and the age of the plants (time during which the space has been occupied).

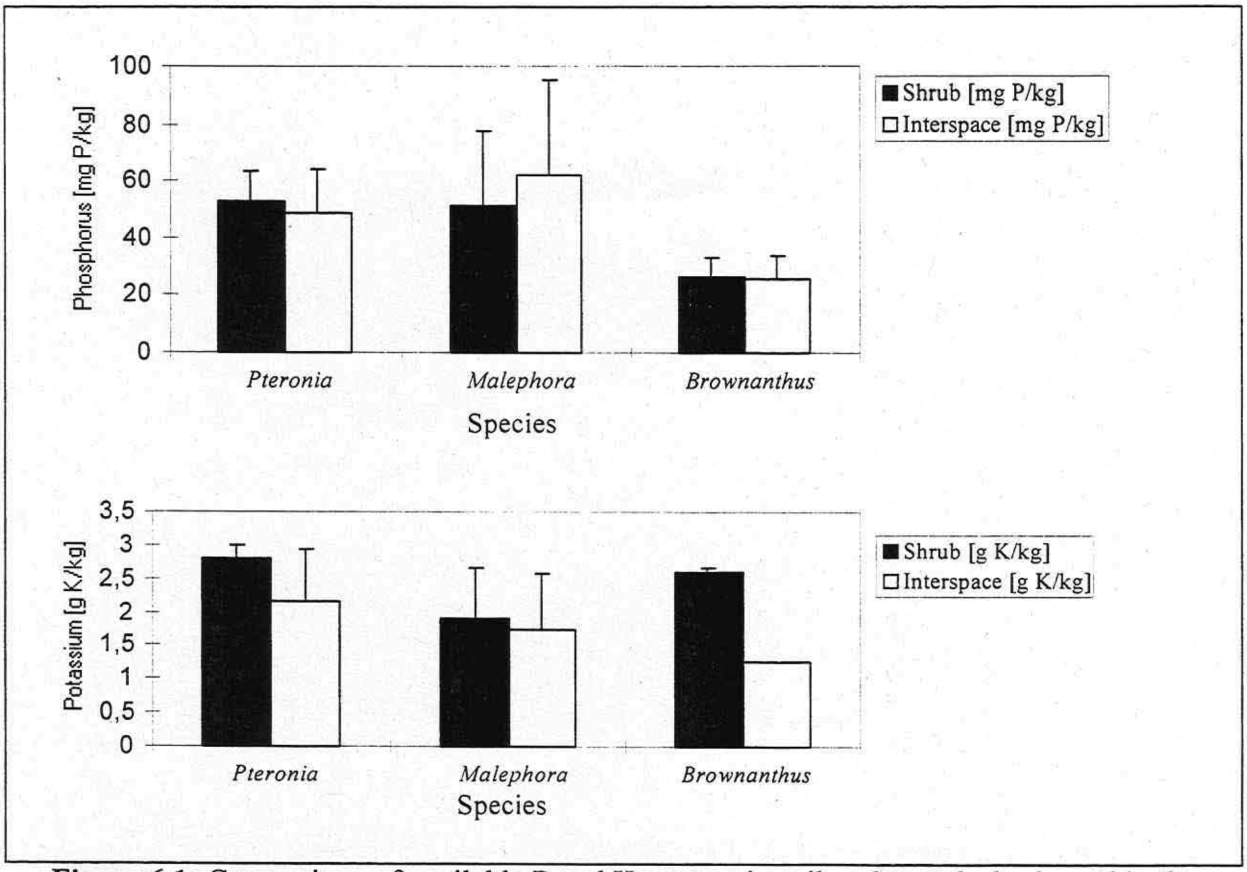


Figure 6.1: Comparison of available P and K content in soil underneath shrubs and in the interspace for different plant species at site C (150 m) of Sandrivier study area.

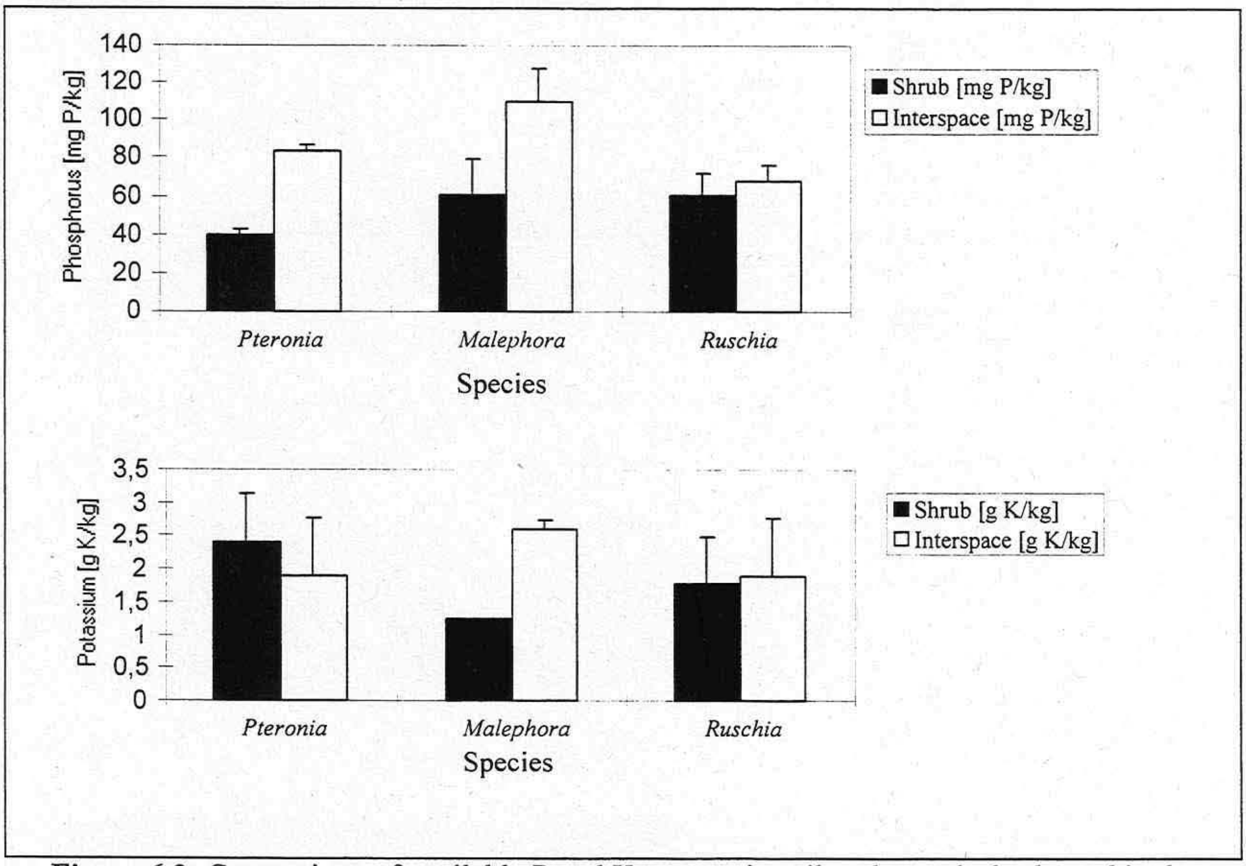


Figure 6.2: Comparison of available P and K content in soil underneath shrubs and in the interspace for different plant species at site E (800 m) of Sandrivier study area.

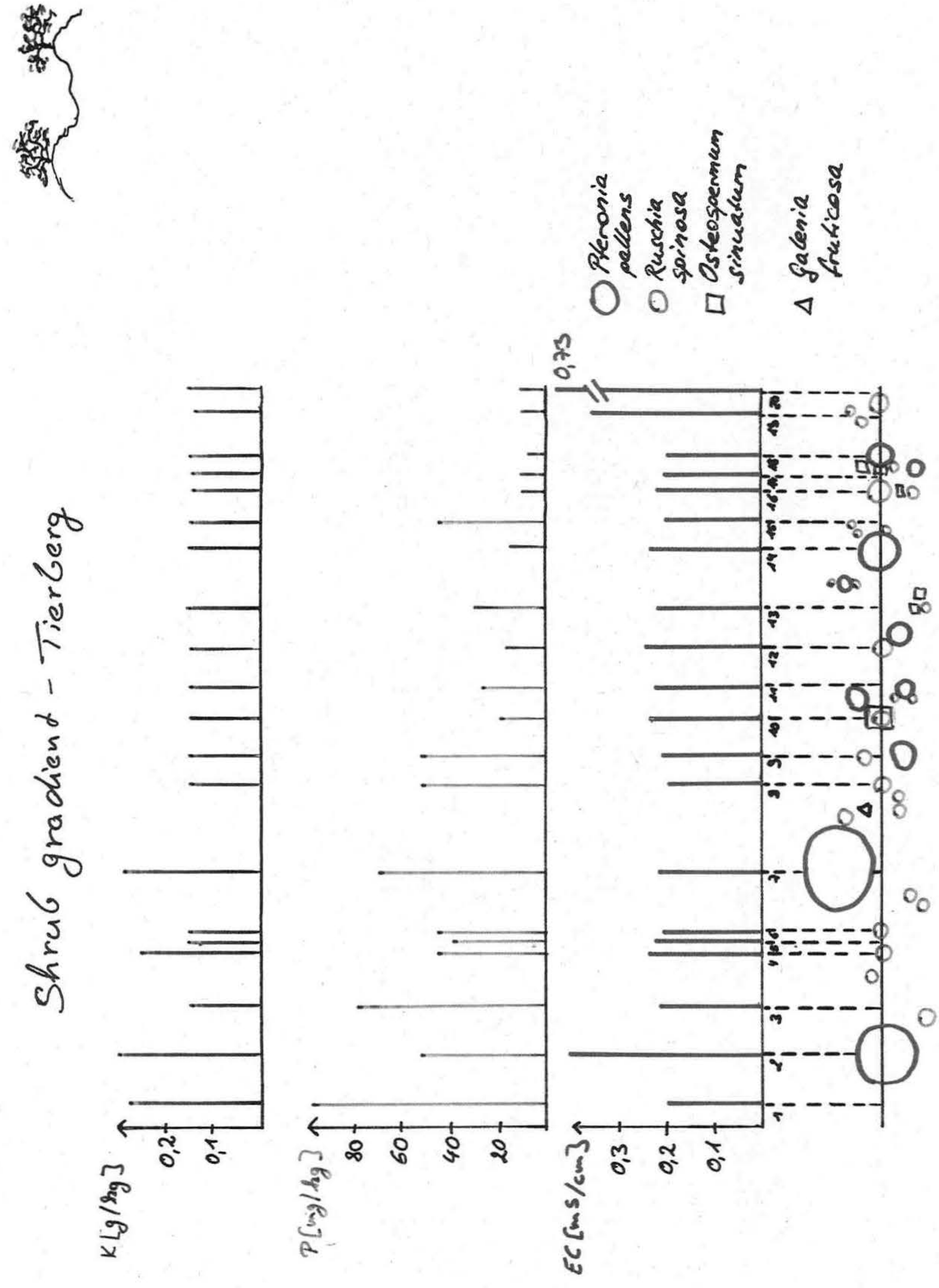


Figure 6.3: Relationship between plant distribution and soil chemical properties along a 15 m transect at Tierberg study area.

It was interesting to notice, that despite all the variability observed with the shrub gradients it could be shown that a plant which is known as a halophyte, *Malephora lutea*, does occur on soil patches with a higher electrical conductivity as would be expected (Table 6.1). At the same time a similar observation was made for *Brownanthus ciliatus*. It should be verified by botanists if this species should be classified as halophyte. So far this plant is known to be typical for base-rich soils in the Karoo. It occurs in areas with a high cation exchange capacity that are also rich in calcium and alkaline. This example of soil-plant interaction could also have some implications for the distribution pattern of plants in the Karoo vegetation in general. It might be thus worth to include it into further point pattern analysis or models on vegetation dynamics. However, a more detailed mapping of soil electrical conductivity and plant species distribution would be required for such an approach.

Table 6.1: Relation between soil electrical conductivity and plant species growing along the transect. Mean values for transects at site C and E are given.

	EC [mS/cm]	
Species	Shrub	Interspace
Brownanthus ciliatus	0.70	1.21
Malephora lutea	0.66	0.74
Pteronia pallens	0.38	0.19
Ruschia spinosa	0.38	0.30

For the heuweltjie a decreasing $CaCO_3$ content was found from the centre to the edge (Fig. 6.4). For the pH-value, no differences existed along the small transect. The pH-value was about 8.9 (data not shown). The EC value of the surface soil decreased with an increasing distance from the centre (Fig. 6.4). The highest salt concentration was measured at the surface in the centre of the heuweltjie. A very high available K content was found in the whole heuweltjie compared to the surrounding (Fig. 6.4). Only in the salt enrichments near the water hole (site A) similar values were found. For the available P the results show no differences along the transect. Only on the edge an unexpected high value was determined (Fig. 6.4).

The nutrient status of a heuweltjie soil should be 2-3 times higher for available P and 3-7 times for available K compared to the soil of the surrounding plains according to MILTON (1995). For the available potassium content the results of this investigation are in agreement with the findings of MILTON (1995). However, the measured values of available P showed no gradient or a higher content in the heuweltjie. Instead of this, a high value was determined in 12 m distance from the centre. This high value cannot be explained and might be due to the heterogeneity of the study area (see chapter 4).

For a further interpretation of the presented results, information would be required about the zoological part of the heuweltjie, i.e. about the age and shape of the underlying termite hill. In addition the investigation of a larger number of heuweltjies would be necessary to assess the extend to which the heuweltjie has an impact on the surrounding area, especially on the soil parameters.

In any case, the heuweltjie was a nutrient and salt enriched patch at the site. Heuweltjies seem to represent heterogeneous structures in soils, which have a high heterogeneity themselves. This must be considered in any investigation.

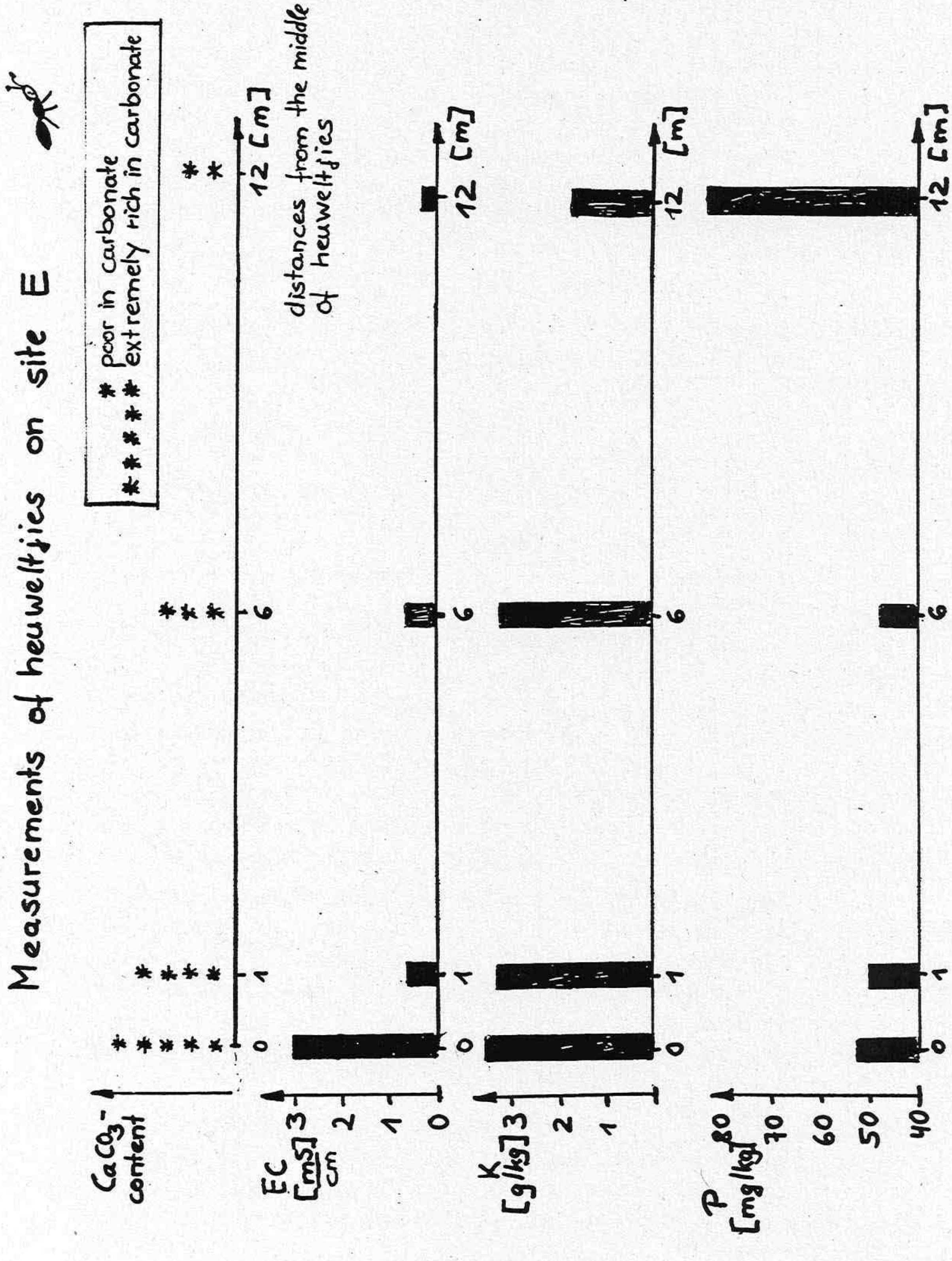


Figure 6.4: Soil chemical properties (0-25 cm depth) along a transect through a heuweltjie at site E (800 m) of Sandrivier study area.

The depth function for pH and EC was integrated in the description of soil profiles and is discussed there (see chapter 4). The available K content in the soil did not change with depth, thus data were not shown. Contrary to the expectations the available phosphorus surprisingly increased and not decreased with the depth. The only explanation for these results seems to be two different layers of soils. This theory is supported by the different deposition cycles (differing in time and origin of soil material) discussed by the Soil Group, however no direct evidence could be derived from the profile descriptions like a marked change in texture between horizons differing in P content.

Table 6.2: P_{DL} - content in the different horizons of the soil profiles at sites B to E of Sandrivier study area.

profile B:

Depth [cm]	P_{DL} [mg/kg]
0 – 15	56.7
15 – 30	53.3
30 – 50	50.0
50 –100	53.3
100 – 125	110.0

profile C:

Depth [cm]	P_{DL} [mg/kg]
0 - 10	23.3
10 - 30	3.3
30 - 60	56.7
> 60	156.7

profile D:

Depth [cm]	P_{DL} [mg/kg]
0 – 5	43.3
5 – 30	15.0
30 – 60	116.7
> 60	83.3

profile E:

Depth [cm]	P_{DL} [mg/kg]
+18 - 0	56.7
0 - 25	76.7
25 - 55	56.7
> 55	110.0

Even if the unexpected high P content in some deeper horizons could be explained by soil genesis, it was still surprising that decomposition of litter at the soil surface, dust deposition or enhanced weathering of soil minerals at the surface did not result in increased content of plant available P in the topsoil as it is usually found. As a consequence topsoil was examined in finer increments, based on the idea that a small enrichment (0-1 cm) might have been masked by diluting this fine layer with soil material from greater depth (1-5 cm).

As the result of this additional investigation, an enrichment of available phosphorus was found in the first centimetre, decreasing rapidly with depth (Fig. 6.5). The average value of the first five centimetres in this investigation was higher than the value of the first ten centimetres of profile C (Table 6.3). Thus it is possible, that a marked P gradient along the piosphere did exist, but was not detected due to the sampling technique applied (see below).

Table 6.3: Average P_{DL} - content in the topsoil compared to A horizon of profile C.

	Depth [cm]	P_{DL} [mg/kg]
Average topsoil	0 - 5	35.78
Profile C	0 - 10	23.30

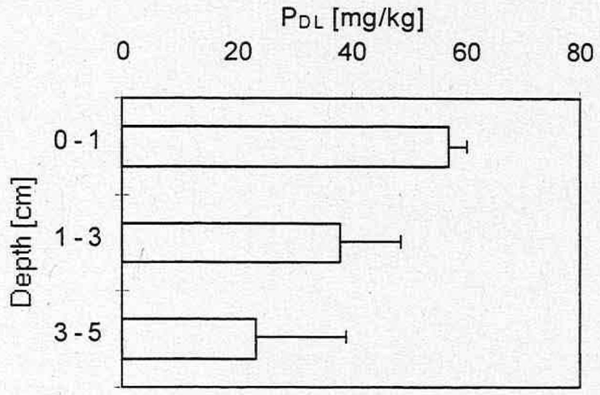


Figure 6.5: P_{DL} - content in different depths at site C of Sandrivier study area.

Finally the question of piosphere gradient for soil chemical properties over the 800 m distance from the water hole (site A) to the "undisturbed vegetation" (site E) could be addressed. For site A, where fluffy soil patches had been observed in the field, the analyses confirmed that these were special features of the site. A salt enrichment in the fluffy soil was found, both in the crust and in the soil below (Table 6.4). In the crusts the salt content was at least 10 times higher than in the interspaces. For pH-, available P and K no differences between the crusts, the fluffy soil and the interspace were measured (Table 6.4).

Table 6.4: Comparison of soil chemical properties between crust and interspace at site A of Sandrivier study area.

EC [mS/cm]	Crust I	Interspace	Crust II
Surface	27.6	1.8	19.3
Depth	17.0		16.2

pH-value	Crust I	Interspace	Crust II
Surface	10.03	10.22	9.92
Depth	10.17		10.16

P_{DL} [mg/kg]	Crust I	Interspace	Crust II
Surface	70.0	70.0	100.0
Depth	66.7		80.0

K_{DL} [g/kg]	Crust I	Interspace	Crust II
Surface	4.2	3.3	3.8
Depth	3.9		3.8

The highest salt content found in the crust was about 30 mS/cm. This value corresponded to 20 g of pure NaCl per litre of water. According to the FAO classification system a soil with an EC > 4 mS/cm in 1:1 extract and a pH of > 8.5 within 0-30 cm is considered as having "salic properties" (FAO UNESCO, 1994).

An explanation for this phenomenon could be the salty water from the water hole. An EC of 1.29 mS/cm was measured for this water. This is high in comparison to the drinking

(EC 0.2 mS/cm). It is possible, that sometimes water was running over the edge of the bore hole or was spilt by the sheep. The water evaporated and left behind the salt, which formed crystals. This may have lead to the formation of crusts and through the expansion during the crystallisation process to the fluffy structure (MÜCKENHAUSEN 1992).

The high soil pH of about 10.0 at site A in the crusts as well as in the interspace indicated that soda (Na_2CO_3) has been formed (SCHEFFER/SCHACHTSCHABEL, 1992).

As no relation between nutrient content and EC was found within site A (Table 6.4) it is likely that the process causing salt accumulation differs from the one resulting in nutrient accumulation. It is possible that nutrient accumulation is due to animal activity (urine, faeces) while salt accumulation results from the evaporation of water.

Even if only the results from the interspace are considered a marked gradient in EC was observed with increasing distance from the water hole (Fig. 6.6). The most pronounced differences occurred within 0 - 150 m. A similar gradient was observed for the soil pH (Table 6.5).

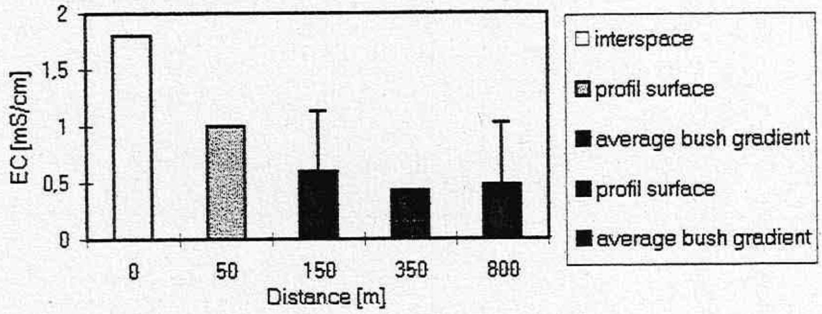


Figure 6.6: Soil electrical conductivity along the piosphere gradient at the study area Sandrivier.

Table 6.5: Soil pH along the piosphere gradient at the study area Sandrivier.

Site	A	B	C	D	E
pH-value	10.10	9.74	8.60	8.48	8.30
Distance [m]	0	50	150	350	800
Explanation	average site A	profile surface	average bush gradient	profile surface	average bush gradient

The available P content also decreased clearly within the first 350 m. (Fig. 6.7). The available P content at 800 m was surprisingly high and did not fit to the other results as discussed above. For the available K, a steady decrease with increasing distance was found (Fig. 6.8). But as a lot of the values were below the measuring range, the results for K remain vague.

However the gradient found for available K in soil corresponds well with the K concentrations in plant press sap (Fig. 6.9). The K concentrations in plant press sap were higher at sites A and B (0-50 m) compared to sites C, D and E (150-800 m).

The EC values of the plant press sap stayed constant along the gradient. But they were higher for *Augea capensis* than for *Malephora lutea* (data not shown).

The decrease of pH and nutrient content with increasing distance from the water hole is in agreement with the results of PERKINS & THOMAS (1993). However, they only observed changes within 50 m around the water hole while TOLSMA et al. (1987) observed changes within 100 m around the water hole. For our study more sampling sites would have been required, pointing to different directions from the water hole to define the size of the piosphere in respect to soil chemical properties more precisely.

It was surprising at first that there was still such a clear gradient of soil chemical properties found at the Sandrivier study area, although no sheep had been grazing on the site for more than three years. However, REID & ELLIS (1995) observed a similar long-term effect in their studies, where they investigated sites, which had served as animals pens and had been abandoned for 20 years. In general the turn over rate is low under the given climatic conditions.

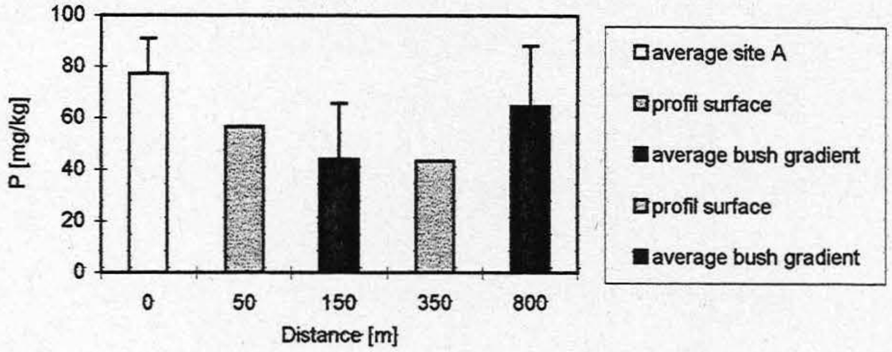


Figure 6.7: Soil available P content along the piosphere gradient at the study area Sandrivier.

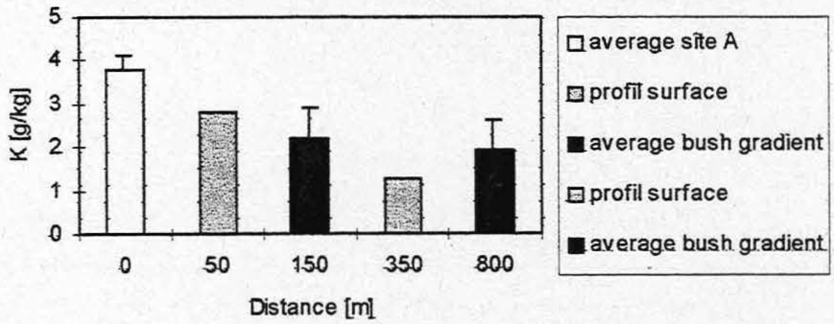
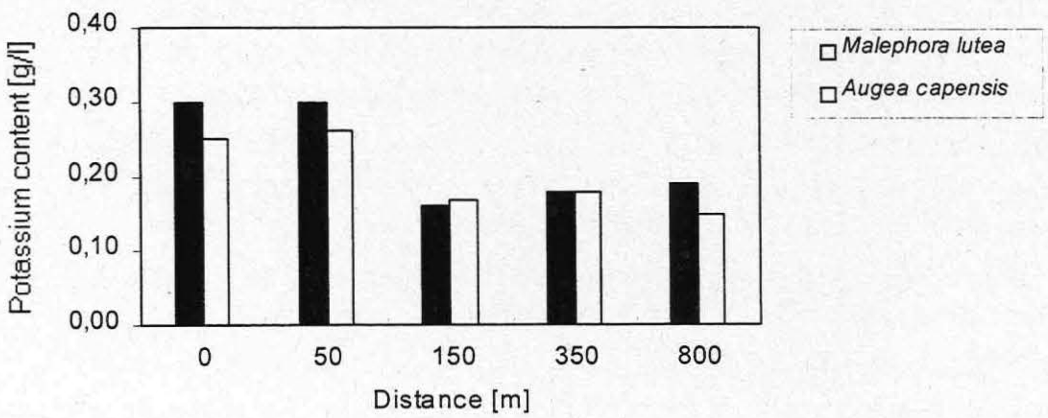


Figure 6.8: Soil available K content along the piosphere gradient at the study area Sandrivier.



6.4 Conclusions

A clear piosphere gradient could be shown for soil chemical properties within 150 m distance. The strong salt accumulation around the water hole, however, is most likely not due to the faeces and urine deposition by sheep like the nutrient enrichment, but rather to evaporation of the saline water pumped up. Although vegetation is obviously the reason for the micro relief at the study area, no nutrient enrichment could be found in this study, which would have elucidated the discussed mechanisms of heap formation. To test the hypothesis of nutrient enrichment underneath the shrubs a more systematic approach with a larger number of replications and measurement of some other variables would be required. Some evidence was obtained for a relation between soil electrical conductivity and the plant species growing on a specific soil patch. It could be interesting to include this knowledge into models on vegetation dynamics.

The heuweltjies are interesting features within the study area with soil chemical properties differing from the surrounding soil. However, more information on origin and age of the structures is required to determine to which extend the surrounding soil is altered by these features.

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6.6 Appendix

Table A6.1: Shrub gradients on site C (150 m from the water hole)

Species (site C)	*Pteronia*	Interspace Pt.	*Malephora*	Interspace M.	*Brownanthus*	Interspace Br.
Phosphorus [mg P/kg]	52.8	48.9	51.1	62.2	26.1	25.6
Standard deviation	10.8	15.4	26.6	33.4	7.1	8.4
Potassium [g K/kg]	2.80	2.15	1.90	1.73	2.60	1.25
Standard deviation	0.21	0.78	0.75	0.84	0.05	0.00

Table A6.2: Shrub gradients on site E (800 m from the waterpoint)

Species (site E)	*Pteronia*	Interspace Pt.	*Malephora*	Interspace M.	*Ruschia*	Interspace R.
Phosphorus [mg P/kg]	39.4	83.3	60.6	110.0	60.6	67.8
Standard deviation	3.9	3.4	18.6	17.6	11.6	8.4
Potassium [g K/kg]	2.40	1.88	1.25	2.60	1.77	1.88
Standard deviation	0.74	0.88	0.00	0.14	0.71	0.88

Table A6.3: Connection shrub shape and nutrient enrichment at site C

Shrub - gradient	Distance [m] (shrub - shrub)	Shrub-shape		Results		
		Diameter [m]	heap height [cm]	EC [mS/cm]	P [mg/kg]	K [g/kg]
Pteronia pallens						
1	2.53	1.10	5	0.19	36.7	2.7
		0.90	10	1.77	43.3	3.2
interspace				0.19	40.0	< 2.5
2	1.75	0 .82	10	0.18	56.7	2.6
		0.80	10	0.18	53.3	2.8
interspace				0.06	66.6	2.6
3	1.65	0.60	4	0.45	63.3	2.7
		0.90	8	0.35	63.3	2.7
interspace				0.14	40.0	2.6
Malephora lutea						
4	1.20	0.50	8	0.44	70.0	not determined
		0.40	3	0.66	96.7	n.d.
interspace				0.30	100.0	2.7
5	1.15	0.25	4	0.33	36.7	2.6
		0.35	3	0.46	40.0	< 2.5
interspace				1.23	50.0	< 2.5
6	0.95	0.25	4	0.33	30.0	< 2.5
		0.25	3	0.38	33.3	2.5
interspace				0.68	36.7	< 2.5
Brownanthus ciliatus						
7	1.00	0.6	8	0.66	20.0	2.6
		0.4	6	0.48	36.7	2.6
interspace				0.74	16.7	< 2.5
8	0.85	0.30	3	0.86	23.3	n.d.
		0.65	4	0.75	23.3	n.d.
interspace				2.53	33.3	< 2.5
9	1.50	0.35	4	0.66	33.3	2.7
		0.35	2	0.79	20.0	2.6
interspace				0.36	26.7	< 2.5

Table A6.4: Connection shrub shape and nutrient enrichment at site E

Shrub - gradient	Distance [m] (shrub - shrub)	Shrub-shape		Results		
		Diameter [m]	heap-height [cm]	EC [mS/cm]	P [mg/kg]	K [g/kg]
Pteronia pallens						
10	1.90	0.70	4	0.36	33.3	n.d.
		0.65	10	0.10	43.3	n.d.
interspace				0.17	86.7	n.d.
11	1.65	0.50	3	0.17	43.3	< 2.5
		0.45	6	0.19	36.7	2.7
interspace				0.3	80.0	2.5
12	1.10	0.65	4	0.34	40.0	2.8
		0.35	4	0.33	40.0	2.7
interspace				0.28	83.3	< 2.5
Ruschia spinosa						
13	1.10	0.32	3	0.29	70.0	< 2.5
		0.40	5	0.75	73.3	2.5
interspace				0.36	66.6	< 2.5
14	0.90	0.37	6	0.27	60.0	< 2.5
		0.40	4	0.27	46.7	n.d.
interspace				0.27	76.7	n.d.
15	1.85	0.40	4	0.30	46.7	2.6
		0.50	10	0.40	66.6	< 2.5
interspace				0.28	60.0	2.5
Malephora lutea						
16	1.20	0.20	5	0.28	53.3	n.d.
		0.25	3	0.48	96.7	n.d.
interspace				0.31	90.0	n.d.
17	0.55	0.28	7	2.96	43.3	< 2.5
		0.35	10	0.39	60.0	< 2.5
interspace				0.84	116.7	2.5
18	0.80	0.30	4	0.30	53.3	< 2.5
		0.4	5	0.98	56.7	< 2.5
interspace				1.05	123.3	2.7

Table A6.5: Shrub gradient at Tierberg

Nr.	Sample-site	Distance [m]	Shrub-height [m]	Shrub-diameter [m]	EC [mS/cm]	P [mg/kg]	K [g/kg]
1	interspace	0.40			0.20	100.0	2.7
2	*P. pallens*	1.50	0.70	1.00	0.41	46.7	3.0
3	interspace	2.30			0.21	80.0	< 2.5
4	*R. spinosa*	3.60	0.15	0.15	0.24	43.3	2.5
5	interspace	3.85			0.22	40.0	< 2.5
6	*R. spinosa*	4.20	0.15	0.30	0.21	46.7	< 2.5
7	interspace	5.30			0.22	70.0	< 2.5
8	*R. spinosa*	7.10	0.15	0.20	0.19	53.3	< 2.5
9	interspace	7.90			0.21	53.3	< 2.5
10	plant-group R, O, P	8.50	0.40	0.90	0.24	20.0	< 2.5
11	interspace	9.40			0.22	26.7	< 2.5
12	plant-group R, P	10.00	0.30	0.60	0.24	16.7	< 2.5
13	interspace	10.80			0.21	30.0	< 2.5
14	plant-group P, R	12.00	0.35	0.60	0.22	13.3	< 2.5
15	interspace	12.60			0.19	46.7	< 2.5
16	plant-group R, O	13.25	0.20	0.50	0.22	10.0	< 2.5
17	interspace	13.50			0.19	10.0	< 2.5
18	plant-group P, O, R, G	14.00	0.20	0.80	0.19	6.7	< 2.5
19	interspace	14.90			0.30	10.0	< 2.5
20	*R. spinosa*	15.40	0.15	0.20	0.73	10.0	< 2.5

(G - Galenia fruticosa, O - Osteospermum sinuatum, P - Pteronia pallens, R - Ruschia spinosa)

Table A6.6: P_{DL} - concentrations in the topsoil

Depth [cm]	P_{DL} [mg/kg]	Standard deviation
0 – 1	56,7	3,4
1 – 3	37,8	10,7
3 - 5	23,3	15,5

Table A6.7: K_{DL} - concentrations [g/l] in the plant press sap

Distance [m]	0	50	150	350	800
Malephora lutea	0.30	0.30	0.16	0.18	0.19
Augea capensis	0.25	0.26	0.17	0.18	0.15

Table A6.8: Soil gradient (EC)

Site	A	A	B	C	D	E
EC [mS/cm]	20.02	1.80	1.00	0.60	0.43	0.48
Distance [m]	0	0	50	150	350	800
Standard deviation	5.22	-	-	0.53	-	0.55
Explanation	average crusts	interspace	profile surface	average bush gradient	profile surface	average bush gradient

Table A6.9: Soil gradient (phosphorus)

Site	A	B	C	D	E
P [mg/kg]	77.34	56.70	44.10	43.30	64.70
Distance [m]	0	50	150	350	800
Standard deviation	13.62	-	21.50	-	23.60
Explanation	average site A	profile surface	average bush gradient	profile surface	average bush gradient

Table A6.10: Soil gradient (potassium)

Site	A	B	C	D	E
K [g/kg]	3.80	2.80	2.18	1.25	1.90
Distance [m]	0	50	150	350	800
Standard deviation	0.32	-	0.71	-	0.70
Explanation	average site A	profile surface	average bush gradient	profile surface (< 2,5)	average bush gradient

Chapter 7

Vegetation composition, ground cover and above-ground biomass

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7.1 Introduction and objectives

The husbandry of sheep in the Karoo is based on the utilisation of natural vegetation for grazing. To assess the impact of grazing, vegetation composition, ground cover, and above-ground biomass were investigated. Vegetation composition reflects site specific effects as soil properties and grazing pressure, ground cover is an important indicator for the erodibility of the soil, and biomass gives hints about the available fodder mass. It has to be kept in mind that not all plants and plant parts are palatable and accessible for the grazing animal. To avoid long-term disturbances or degradation of the ecosystem an appropriate stocking density of sheep has to be maintained. Places around water holes are influenced by the comparatively high concentration of livestock which is finally reflected in the vegetation composition.

7.2 Methods

7.2.1 Vegetation composition

The -method of BRAUN-BLANQUET (1964) was used to investigate the plant composition in the study areas. At each study site 2 or 3 sample sites were chosen, each plot being 10 x 10 m² in size. On each sample site (sites B,C,D, and E at Sandrivier, and one site at Tierberg; compare chapter 1) all species found have been identified and the percentage of coverage of each species was estimated.

7.2.2 Ground cover

On each site at (Sandrivier B, C, D, E, and one site at Tierberg) 100 plots were chosen by random. To estimate the ground cover a wooden frame with ten pin-holes linearly placed in a distance of 10 cm from each other was used (point-frame method). Ground cover was estimated by putting a metal pin through each of the 10 holes and counting the hits of vegetation per frame and plot (compare Picture 24). Additionally, it was counted, how often the species *Pteronia pallens* was hit. Ground cover was also estimated using a sunfleck-ceptometer, a measuring instrument with a sword with photo-sensitive cells. Quantification was based on the percentage of sunlight reaching the ground, indicating the percentage of ground not shadowed by vegetation. The plots for this measurement were the same as for the point-frame method, thus a subsequent correlation analysis could be performed.

7.2.3 Biomass

To estimate the above-ground biomass at each site along the Sandrivier transect, vegetation was cut at ground level in two rectangular plots of 2 x 1 m² (compare Picture 25). Fresh weight of each plant species within the plot was determined. Dry matter content was assessed by freezing of subsamples of the species *Pteronia pallens*, *Drosanthemum* spp., *Ruschia spinosa*, *Augea capensis* and *Malephora lutea* and subsequent drying in the oven (104° C). For other species found within the sample plots, dry matter content of the succulent and the non-succulent species was estimated by using the average of the succulent species and the dry matter content of *Pteronia pallens* respectively. The values given in Table 7.1 are the averages of the two sample plots per site.

Table 7.1: Dry matter content of plant species analysed

Plant species	Dry matter content (% of the fresh matter)
Augea capensis	24.6
Drosanthemum ssp.	31.6
Malephora lutea	29.8
Ruschia spinosa	45.8
Pteronia pallens	79.5
average of the succulent species*	**32.9**

* (*Augea capensis, Drosanthemum* spp., *Malephora lutea*, and *Ruschia spinosa*)

7.3 Results

7.3.1 Vegetation composition

The results of the assessment of the vegetation composition according to Braun-Blanquet (1964) are listed in Table 7.2. Total number of species was 40. Vegetation composition changed along the gradient as can be seen in Table 7.2. The plant species can be put into some rather distinct ecological groups:

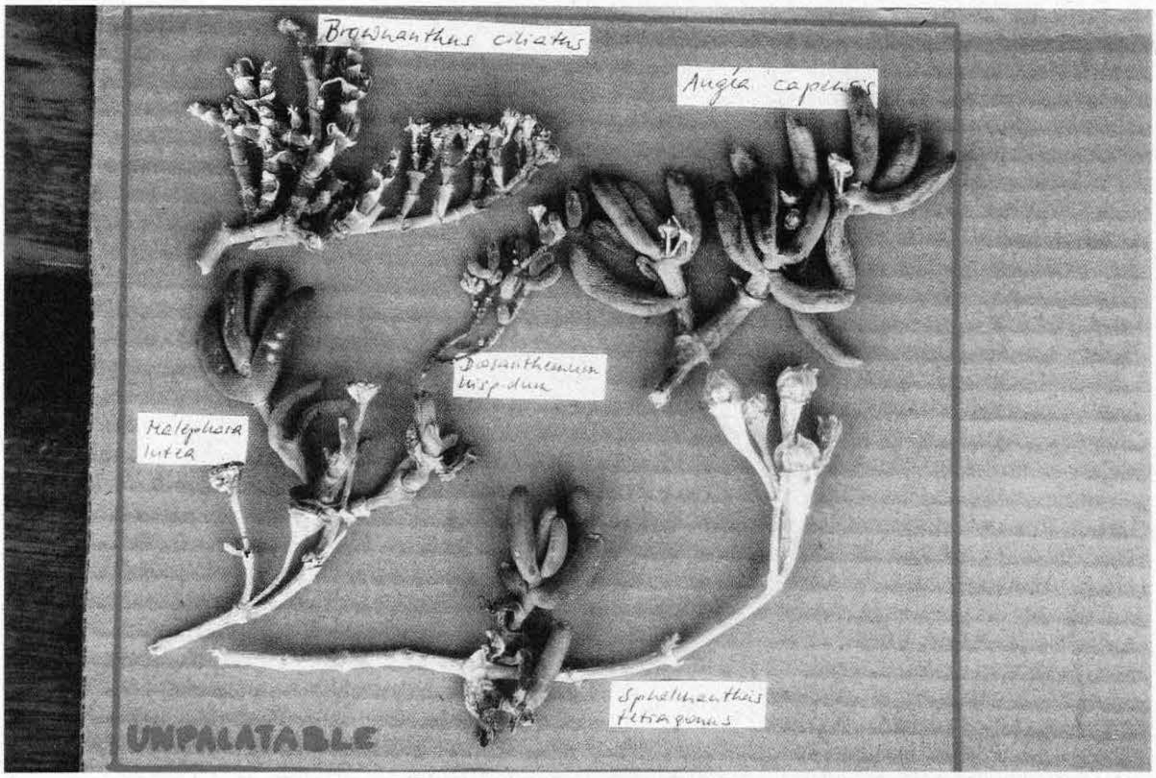
- First, there is the group of unpalatable plants (compare Picture 26) which were found mainly on sites B and C. Most of these plants are colonisers and live only for a few years. Some of them are well adapted to salty soils, like *Augea capensis* which accumulates potassium. Species of this group seem to be quite resistant against trampling. Only one plant of this group is palatable: *Drosanthemum hispidum*, but it is also a short-living plant (almost annual) and its leaves are very close to the ground so that the sheep possibly cannot eat them.

- The second group consists of palatable plants (compare Picture 27) that are present mainly on sites D, E, and on the Tierberg sample site. The reason why they were not found near the waterhole could be their palatability, resulting in an extinction respectively destruction at this site caused by high grazing pressure and trampling impact. Another reason for their absence could be that these plants do not tolerate as high salt concentrations in the soil as have been found there (see chapter 6 by KAHLE et al.). *Hereroa lutea* is actually unpalatable, but its flowers are very palatable for sheep and so it can not reproduce at localities where all the flowers are eaten.

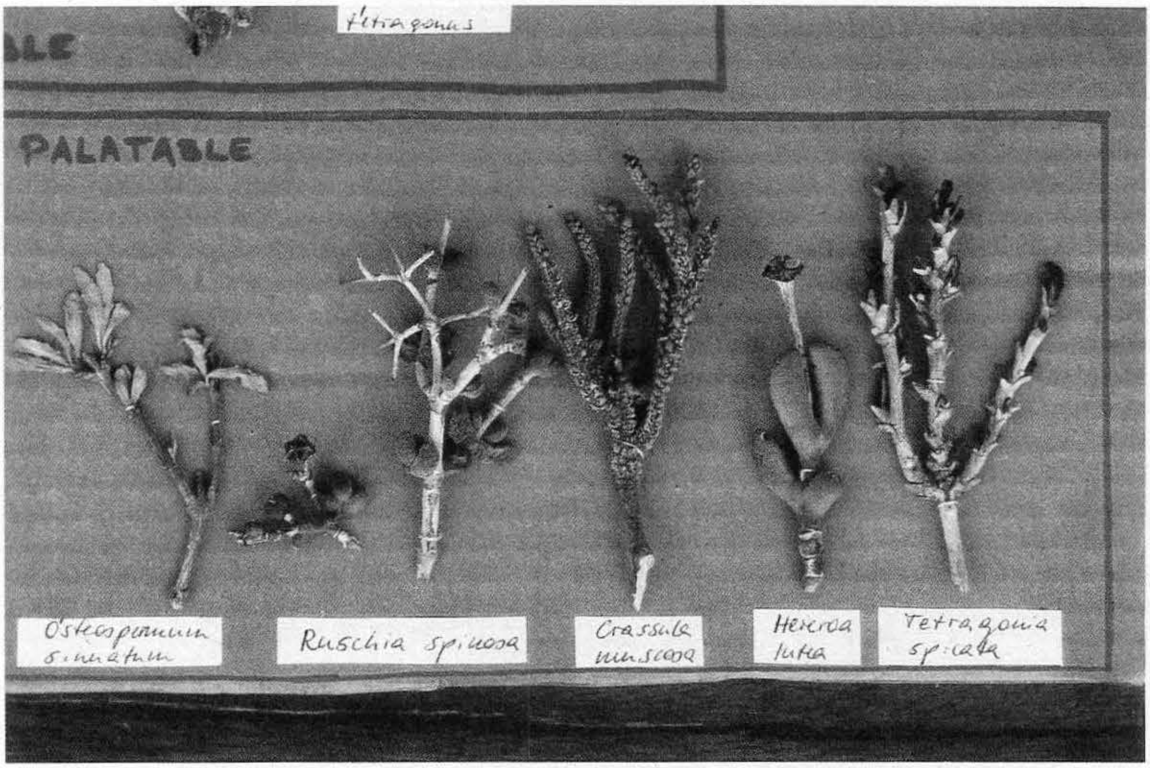
Picture 24:

Ground cover estimates by use of a wooden frame (compare chapter 7.2.2; "Tierberg", March 1998)

Picture 25: Vegetation removal for above ground biomass estimates (compare chapter 7.2.3; March 1998)



Picture 26: Most important ***unpalatable*** plant species of the research area (March 1998)



Picture 27: Most important ***palatable*** plant species of the research area (March 1998)

Table 7.2: Vegetation composition in Sandrivier and Tierberg
(coverage estimates after BRAUN-BLANQUET 1964)

	sample site	**B1**	**B2**	**C1**	**C2**	**C3**	**D1**	**D2**	**D3**	**E1**	**E2**	**E3**	**T1**	**T2**	**T3**
	number of species	15	9	11	16	14	15	13	13	20	13	15	11	17	13
	total coverage (%)	30	30	20	20	15	20	10	15	25	15	20	20	30	20
	max. height (cm)	30	30	55	55	40	50	55	40	45	60	60	50	70	55
u	*Malephora lutea*	2b	2a	2a	2a	1	2a	1	2m	2a	+	2m	.	+	.
u	*Augea capensis*	2m	2a	1	1	1	+	+	+	1	+	+	.	.	.
u	*Brownanthus ciliatus*	2m	+	+	+	2m	.	.	.	+	.	+	.	1	+
p	*Drosanthemum hispidum*	1	1	1	+	1	+	.	+	+	.	.	.	+	.
u	*Sphalmanthus tetragonus*	1	1	1	1	1	1	.	.	+	.	+	.	.	.
u	*Atriplex lindleyi*	+	1	.	.	.	.	.	.	1	.	1	.	+	.
u	*Pteronia pallens*	+	+	2a	2a	2a	2a	2a	2m	2a	2a	2a	1	1	1
u	*Sphalmanthus brevifolius*	.	.	1	1	.	+	.	.	+	.	.	+	+	.
p	*Ruschia spinosa*	.	.	.	+	+	2a	1	+	2a	2a	2m	2a	2a	2m
p	*Osteospermum sinuatum*	+	.	.	+	1	+	1	+	2m	1	1	2a	2m	1
p	*Tetragonia spicata*	.	.	.	+	.	1	+	1	+	.	+	+	.	+
p	*Crassula muscosa*	.	.	.	.	.	.	+	.	+	.	.	.	+	.
u	*Hereroa lutea*	.	.	.	.	.	.	.	.	+	1	+	1	1	1
p	*Drosanthemum montaguense*	1	1	.	+	+	1	1	2m	2m	2a	1	.	.	+
u	*Galenia fruticosa*	+	.	+	+	+	.	+	.	.	+	+	2a	1	1
u	*Cuspidia cernua*	+	.	1	+	+	+	+	+	+	.	.	.	.	.
u	*Sphalmanthus nitidus*	.	.	+	+	+	+	+	(+)	.	+	+	.	.	.
p	*Aridaria noctiflora*	.	.	+	+	.	1	.	+	.	.	.	.	.	.
u	*Lycium cinereum*	+	.	.	.	.	.	.	.	.	+	+	.	.	.
u	*Chrysocoma ciliata*	+	.	.	.	.	.	.	.	.	.	.	.	+	+
u	*Drosanthemum uniflorum*	.	+	.	+	.	.	+	.	.	.	.	.	.	.
p	*Crassula deltoidea*	.	.	.	.	+	.	.	1	.	.	.	.	.	.
u	*Pteronia sordida*	.	.	.	.	+	.	+	.	.	.	.	.	.	.
u	*Ornithogalum* spp.	.	.	.	.	.	+	.	.	+	.	.	.	.	.
p	*Salsola tuberculata*	.	.	.	.	.	.	.	.	+	+	.	.	.	.
u	*Eriocephalus spinescens*	.	.	.	.	.	.	.	.	+	.	+	.	.	.
p	*Kochia salsaloides*	+	.	.	.	.	.	.	.	.	.	.	.	.	.
p	*Galenia papulosa*	+	.	.	.	.	.	.	.	.	.	.	.	.	.
p	*Euphorbia caterviflora*	.	.	.	.	.	+	.	.	.	.	.	.	.	.
p	*Fockea crispa*	.	.	.	.	.	.	.	.	+	.	.	.	.	.
p	*Pteronia viscosa*	.	.	.	.	.	.	.	.	+	.	.	.	.	.
u	*Sarcocaulon* spp.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
u	*Kleinia longiflora*	.	.	.	.	.	.	.	.	.	+	.	.	.	.
u	*Asparagus* spp.	.	.	.	.	.	.	.	+	.	.	.	.	+	.
p	*Crassula subaphylla*	.	.	.	.	.	.	.	.	.	.	.	+	2m	1
p	*Pteronia empetrifolia*	.	.	.	.	.	.	.	.	.	.	.	1	1	+
p	*Zygophyllum cf microphyllum*	.	.	.	.	.	.	.	.	.	.	.	.	2a	+
p	*Gazania krebsiana*	.	.	.	.	.	.	.	.	.	.	.	1	1	.
u	*Ruschia approximata*	.	.	.	.	.	.	.	.	.	.	.	.	.	1
u	*Drimia anomala*	.	.	.	.	.	.	.	.	.	.	.	+	.	.

u-unpalatable,	p-palatable
+: 1 - 5 individuals/sample site; coverage: < 5%	2b: any number of indviduals; coverage: 16- 25%
1: 6 -50 individuals/sample site; coverage: < 5%	3: any number of indviduals; coverage: 26- 50%
2m: >50 individuals/sample site; coverage: < 5%	4: any number of indviduals; coverage: 51- 75%
2a: any number of indviduals; coverage: 5- 15%	5: any number of indviduals; coverage: 76-100%
B, C, D, E: Sandrivier study sites	T: Tierberg study sites

- Between those two groups there are some plants that show a different behaviour: One is *Atriplex lindleyi*, which is a plant introduced from Australia as a fodder plant for the ostriches. It is an indicator for disturbances. Under low grazing pressure it is only found on heuweltjies. In Sandrivier it was mainly present at site B, indicating that this is the most disturbed site.

- Another differently behaving plant is *Pteronia pallens*, which reaches an age of up to 200 years. It was found on every sample site, but only in very low abundance on site B. A quite high abundance of *Pteronia pallens* was found on site C. The low abundance at site B could be due to the fact that the seedlings do break easily so that the plant can not reproduce in a heavily trampled area. Another hypothesis is that the seedlings are not resistant against the high salt concentrations in the soil. *Sphalmanthus brevifolius* is in a way a follower of *Pteronia pallens*. It grows under shrubs like *Pteronia* spec. or *Lycium* spec., because it needs permanent shadow and is therefore not present at site B, because the plants found here are mainly short-lived and do not give permanent shadow. Some of species were not found at both study sites, like *Pteronia empetrifolia*, which was present only at Tierberg. It grows only at a lower pH. But most of these species found behave either indifferently to the conditions or had too low abundances at the sample sites for further conclusions about their preferences.

7.3.2 Ground cover

The mean ground cover of the vegetation was 25.0 % for Sandrivier and 29.5 % for Tierberg (Tab. 7.3). In Sandrivier the highest ground cover was found for site B in 50 m distance to the watering point. The lowest ground cover was found in 150 m distance to the watering point. The value found in Tierberg was high compared to the average ground cover of 25.6 % found in 1989 by MILTON (1990). Probably the ground cover in Tierberg has increased in the last 9 years due to protection of the vegetation from grazing by sheep.

A comparison of the ground cover at the different sites by analysis of variance showed significant differences between B and C and between B and Tierberg. A difference between the overall mean of the ground cover at Sandrivier and Tierberg could not be stated (tested with t-test). An estimation of the ground cover with the sunfleck-ceptometer showed lower values than that with the point-frame method. The values assessed by the two methods were nevertheless correlated. The correlation coefficient was significant (with $r^2 = 0.6$). Ground cover of the single species *Pteronia pallens* alone was about 4 % for Sandrivier and 3.4 % for Tierberg. At Sandrivier a significant difference between site B and C was found.

Table 7.3: Ground cover (%) of the vegetation in Sandrivier and Tierberg

Site	**Method**		
	Point-frame (total vegetation)	**Point-frame (*Pteronia pallens*)**	**Sunfleck-ceptometer**
Sandrivier - B	32.4^a	0.8^a	22.7
Sandrivier - C	19.0^b	6.4^b	11.0
Sandrivier - D	23.2	4.5	16.7
Sandrivier - E	25.6	4.2	15.5
Sandrivier - average	25.0	4.0	16.5
Tierberg	29.5^a	3.4	-

The values are significant different when marked with different index letters. Differences were tested by ANOVA and Scheffé-test.

7.3.3 Biomass

The overall mean for the above ground biomass for Sandrivier was 2.17t dry matter/ha. This value is low compared to the 3.27 t dry matter/ha assessed by MILTON (1990) in 1989 in Tierberg (Tab. 7.4). It has to be taken into consideration that the number of sample plots at Sandrivier was too low for a proper analysis.

Table 7.4: Above ground biomass (t DM/ha) of the vegetation at Sandrivier and Tierberg

Site	Biomass in t dry matter per ha
Sandrivier - B	1.8
Sandrivier - C	1.6
Sandrivier - D	3.45
Sandrivier - E	1.8
Sandrivier - average	2.17
Tierberg	3.27 (MILTON 1990)

6.4 Conclusions and summary

Up to a distance of 150 m from the watering place it was found that unpalatable plants were dominating. At 350 m as well as at 800 m distance, palatable plants dominated the plant communities at Sandrivier. The vegetation composition 800 m away from the watering point was rather similar to that of Tierberg. Generally, with decreasing grazing pressure, as it was assumed for the increasing distance to the watering point (compare chapter 1), the portion and vitality of palatable plants was increasing. The highest vegetation coverage was found close to the watering place, the lowest at 150 m distance. One might have expected an increasing coverage with increasing distance. The peak at the distance of 50 m can be explained by the maximum portion of succulents and annual plants at these sites. Highest coverage does not mean highest biomass as the water content of succulents is about 80 %.

The coverage of *Pteronia pallens*, a plant which establishes slowly and reaches an age of over 100 years, reached its maximum at study site C. At the sites in larger distances it was found regularly but not as frequent as at 150 m distance. As a poisonous shrub *P. pallens* is resistant against browsing but not necessarily against trampling, what explains that it reached its maximal coverage under a relatively high browsing pressure, but not at the sites with maximal trampling pressure.

The number of species did not increase along the gradient, as there was quite a portion of colonisers and annuals at site B. Even at Tierberg a particularly high species diversity could not be found. It would probably have been found if the investigations were done at a larger scale. The BRAUN-BLANQUET-method, which was used for the vegetation analysis, documents vegetation composition and coverage. To describe the typical patchiness of the Karoo Veld other methods like the line-intercept-methods might be more suitable.

Both studies, the vegetation analysis and the coverage estimation, showed clear differences firstly between site B and C and again between site C and D. From a botanical point of view the boundaries from high to low impacted vegetation within the pioshere run here.

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Picture 28:

Augea capensis, one of the most abundant unpalatable plants on the research sites (March 1998)

Chapter 8

Spatial patterns in semi-arid Karoo vegetation: A comparison of grazed and protected rangelands

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ABSTRACT

The analysis of point patterns in vegetation by means of spatial statistics, mostly by RIPLEY'S K-function, has become increasingly popular in the last years. Recently, a new method was introduced by PODANI & CZÁRÁN (1997), combining the K-function with an information-theory approach. Hereby the mean compositional information of a pattern at a certain scale is calculated from the occurrence probabilities of the observed species combinations within circles around each plant and compared to expected values. The overall deviation from randomness and also the individual species contributions to it can be plotted against increasing radius. The method has been suggested as a tool for analysis of multi-species patterns and for detection of assembly rules and keystone species. We tested the new technique in practice by applying it to spatial data from grazed and ungrazed shrub communities of the semi-arid Karoo, South Africa. At small scales (10-50 cm), we found a positive deviation at the ungrazed and a negative deviation at the grazed site, indicating small-scale aggregation and repulsion, respectively. At larger scales, there was positive deviation from randomness from 60 to 200 cm at the ungrazed site, originating from clumped distribution of some species. The grazed site showed a random pattern again above 150 cm, which we interpret as homogenising effect of disturbance, superimposing a new pattern on vegetation and thereby eliminating natural patchiness. The results showed that species had a different share in the overall pattern and that there was a higher variability in species contributions at the ungrazed site. In summary, the new method by PODANI & CZÁRÁN seems to perform well in that it detected characteristic scales of pattern in Karoo vegetation. In addition, it identified species that play an important role in formation of that pattern. It does not provide information, though, on how many and which other species are affected by these keystone species. An interpretation of the results in terms of explicit assembly rules is therefore highly speculative, and it has to be asked if a bivariate K-function is not more appropriate when such questions are to be addressed.

8.1 Introduction

Plant communities are not random assemblages of species, but their composition and structure are at least to a certain degree determined by biotic and abiotic factors. Therefore, vegetation may be expected to show spatial and temporal patterns at characteristic scales. For example, interspecific competition may pose a limit to the number of possible co-occurences of species, which could be important at small but less relevant at larger spatial scales (BENGTSSON et al. 1996). However, at larger scales e.g. climatic constraints and landscape history may determine the size and composition of the local species pool (SHMIDA & ELLNER 1984, ZOBEL 1997), whereas at smallest scales, soil heterogeneity and stochastic processes may be of greater importance (CHESSON 1986, WILSON 1990).

While the existence of non-random patterns is today widely accepted (WEIHER & KEDDY 1995), it is in practice still difficult to identify the processes that are responsible for certain patterns in such a way that testable predictions about community structure are possible. However, in order to attain an understanding of vegetation structure, the first step is to identify patterns and the characteristic scales at which they occur with adequate methods.

An exact and intuitively appealing method of detecting spatial patterns in vegetation is the statistical analysis of point mappings in which locations of all plant individuals are recorded. Hereby it is tested if the observed spatial distribution departs significantly from the null hypothesis of complete spatial randomness. The most popular technique for such analyses has been RIPLEY'S K-function (RIPLEY 1981, 1987), which was recently modified by PODANI & CZÁRÁN (1997), who combined the K-function with the information-theory approach of JUHÁSZ-NAGY (1993, JUHÁSZ-NAGY & PODANI 1983). Both techniques have the advantage that patterns are being examined over a range of spatial scales, so that the characteristic scales at which they occur can be detected.

In this study we will use the technique of PODANI & CZÁRÁN (1997) for an analysis of Karoo vegetation at small scales (<1m). Thereby we will address three questions:

- How does the method quantify the visible patterns in Karoo vegetation and which invisible ones does it detect further? In particular: in which way do the most frequent species contribute to the overall vegetation pattern?
- In which way do patterns in grazed vegetation differ from those in protected vegetation?
- Is this method, which has not yet been sufficiently tested in practice, generally applicable to the particular conditions in the Karoo?

The Karoo is a very suitable area for such analysis of point patterns, since vegetation is sparse, with an average cover of 18% and only 3 to 7 plant individuals m^{-2} (MILTON et al. 1992), which makes the determination of the location of each plant individual possible. Another feature of Karoo vegetation is that it is largely dominated by few shrub species. Thus there is a possibility to reduce sampling and computational effort without losing much information when analysis is restricted to the most abundant species.

8.2 Methods

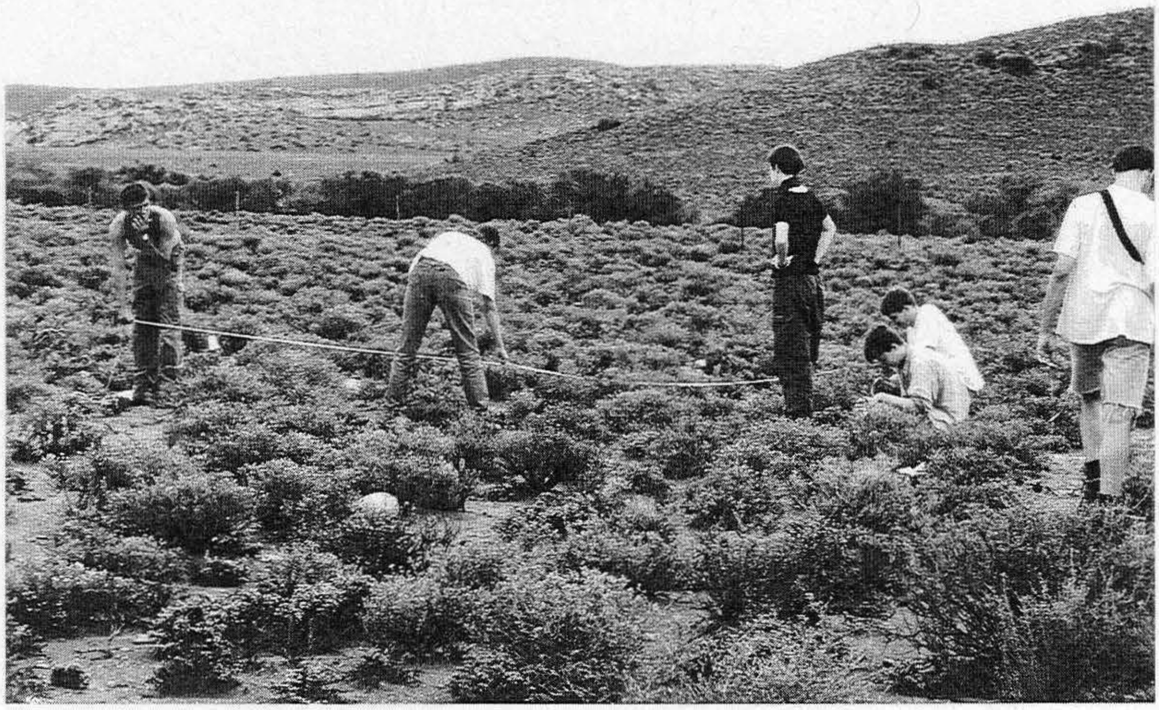
8.2.1 Data collection

We chose two 15x15m plots, one at the Tierberg Karoo Research Centre (protected from grazing since 1987; compare Pictures 29 and 30) and one at Sandrivier (grazed; site E; compare chapter 1 for characterisation of sites). These plots were set up on plain areas of rather homogeneous vegetation, avoiding to include 'heuweltjies', which differ markedly from the surrounding areas in terms of soil and vegetation composition (MILTON et al. 1992).

Within each plot we recorded the exact positions of all established shrubs. In this respect, plants with a height of more than 10 cm were considered to be established. Since in some shrub species it is difficult to decide whether two shoots belong to different individuals or have a connection below soil surface, we considered two shoots as different individuals if they grew more than 10 cm apart. We determined the rectangular coordinates of the plants by using a triangulation method, which is considered to be more exact than direct measurement.

8.2.2 Species

We selected six abundant species for separate recording, but lumped all other species into one category. It seemed reasonable to us to choose five species on which previous research has particularly focused on and of which there exists an extensive knowledge of their life-histories: *Brownanthus ciliatus* (Mesembryanthemoideae), *Ruschia spinosa* (Ruschioideae), *Galenia fruticosa* (Aizoaceae), *Pteronia pallens* (Asteraceae) and *Osteospermum sinuatum* (Asteraceae). For details see WIEGAND et al. (1995) and the references therein. We included a sixth species, *Malephora lutea* (Ruschioideae), because of its high abundance at Sandrivier.



Picture 29 & 30: Within 15x15m² plots the exact positions of all established shrubs have been recorded (Tierberg Karoo Research Centre; March/April 1998)

8.2.3 Analysis of spatial pattern

For the analysis of spatial pattern we used the computer program DARIUS by PODANI & CZÁRÁN (1997). The program places circular plots with increasing radii around each plant and determines the species combinations within them. In our study plot radii were ranging from 10 to 200 cm. It is possible to assign to each species combination a certain 'compositional information', which depends on the probability of occurrence of that combination under complete spatial randomness, which in turn basically depends of the overall abundances of the species. Species combinations with low probabilities of being detected have high values of compositional information, whereas combinations that should appear frequently under random conditions have low compositional information. From the values of compositional information of all plants the program calculates the 'mean compositional information'(MCI) of the whole pattern for a certain radius.

Comparison between the observed MCI for the field data to the expected MCI under a null model of complete spatial randomness provides a measure ΔMCI of the departure from randomness. Moreover, the individual contribution of each species to the overall ΔMCI is being calculated. To test for significance of the departure from randomness, the program calculates 95% Monte Carlo confidence envelopes by analysis of 19 simulated maps with the same species abundances as in the field data. For a more detailed description of the method see PODANI & CZÁRÁN (1997).

8.3 Results

We recorded a total of 1014 and 930 plant individuals in Tierberg and Sandrivier, respectively (Tab. 8.1). The numbers of individuals were sufficiently large to provide a reasonable set of data for the statistical analysis. There is considerable difference, though, in the relative abundances of single species between the two study sites (see Tab. 8.1).

Table 8.1: Numbers of individuals of the species recorded in 15x15m square plots in protected (Tierberg) and grazed (Sandrivier) Karoo rangelands.

	Tierberg	Sandrivier
Galinea fruticosa	303	-
Malephora lutea	-	364
Osteospermum sinuatum	144	21
Pteronia pallens	20	212
Ruschia spinosa	392	162
Others	155	171
Total	1014	930

To give an impression of the size of our data sets, the share of each species in them, and how the individual species distributions look like, scatterplots for the species are displayed in Fig. 8.1 and Fig. 8.2. These pictures may also be used in combination with the calculation results to compare the abstract MCI indices with the real distribution of the species.

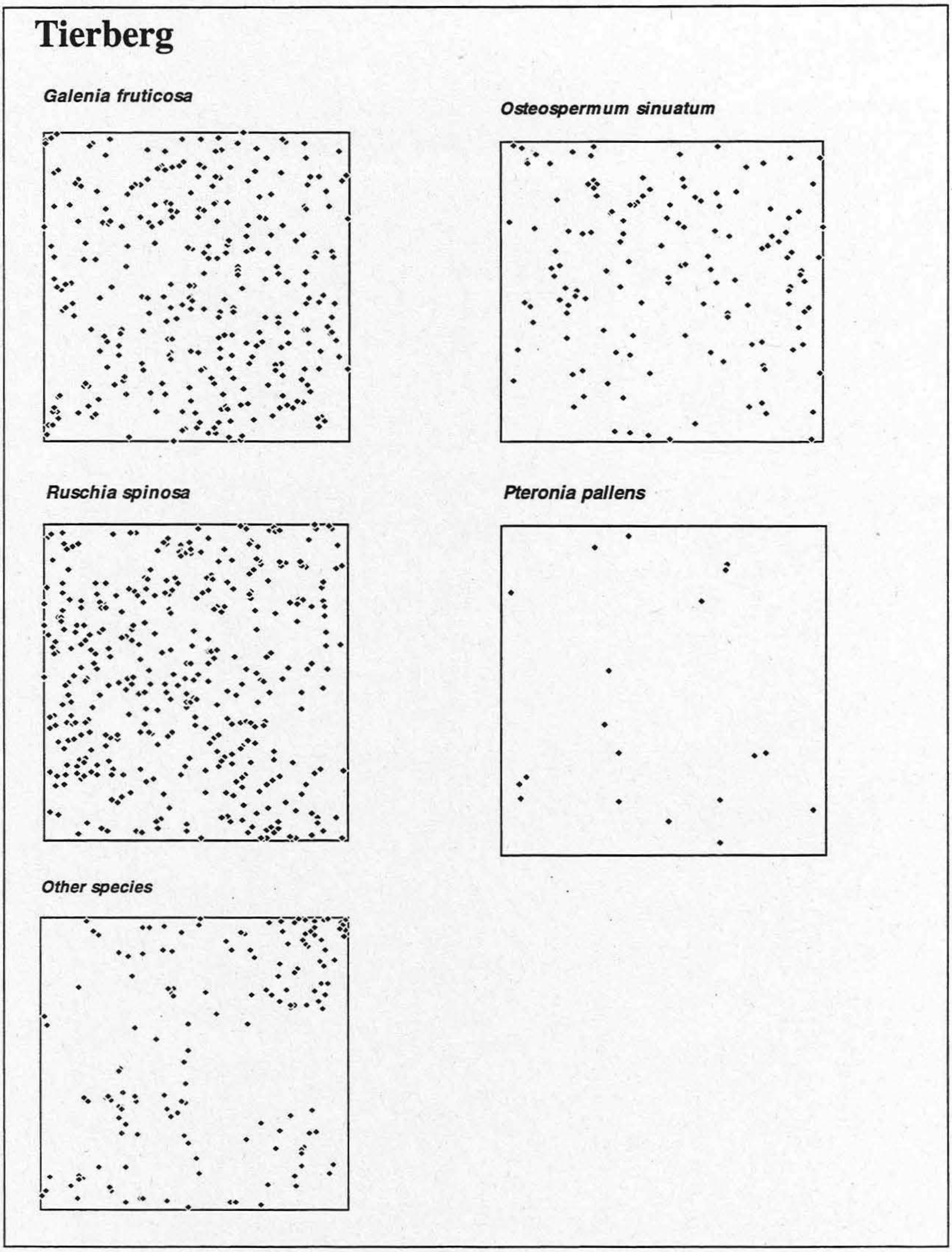


Figure 8.1:
Spatial distributions of the recorded species in a 15x15m² plot at 'Tierberg' (protected area). The last plot, 'Other species', displays the combined distribution of several species that were lumped in that category.

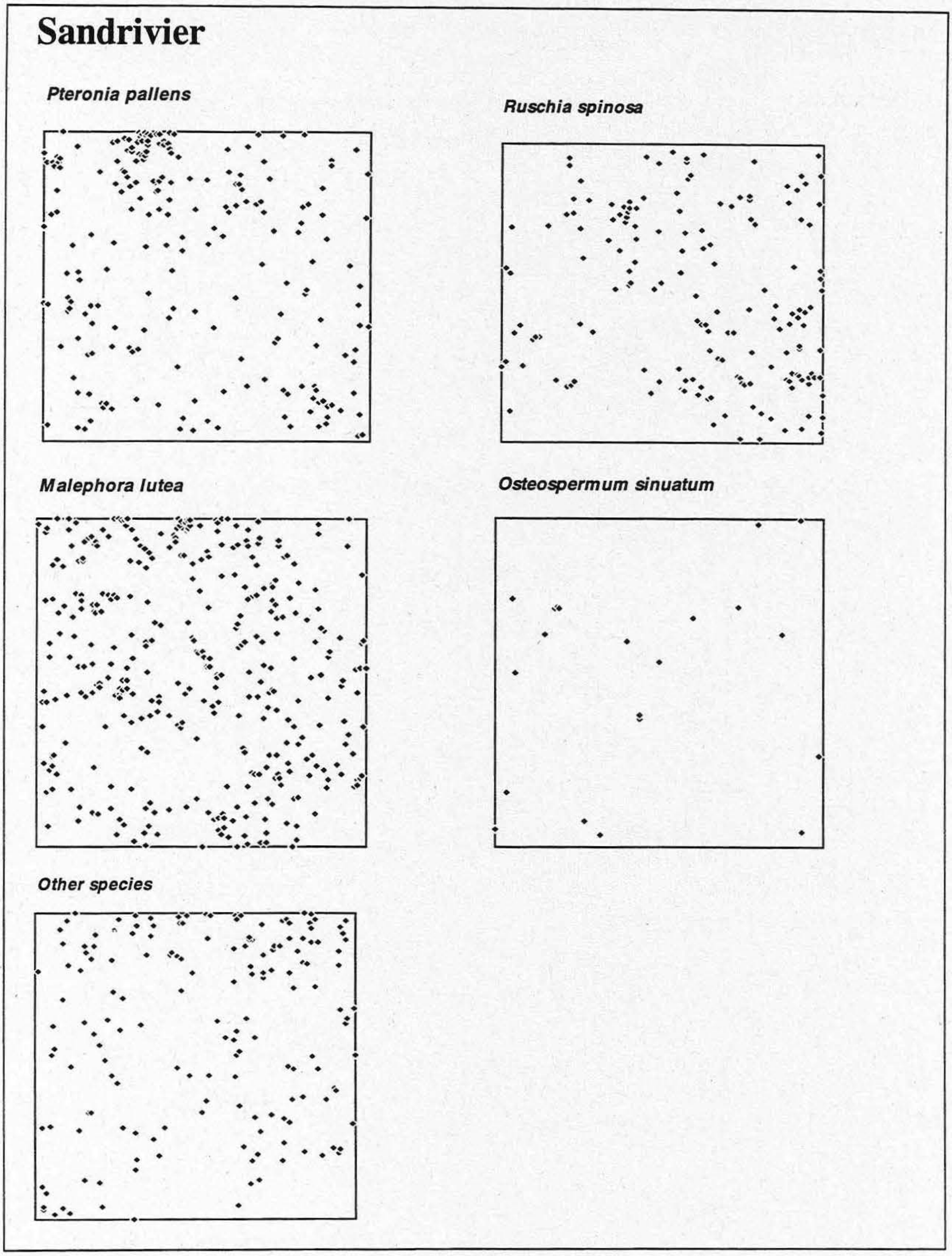


Figure 8.2:
Spatial distributions of the recorded species in a 15x15m plot at 'Sandrivier' site IV (grazed area). The last plot, 'Other species', displays the combined distribution of several species that were lumped in that category. Not shown is *Brownanthus ciliatus*, which occurred with only one individual.

For the Tierberg data we found a significant positive deviation in ΔMCI at a scale of 10-30 cm and another above 90 cm (Fig. 8.3A). This patterns is generally repeated in the individual curves of the most abundant species *Galenia fruticosa, Osteospermum sinuatum* and *Ruschia spinosa*. The remaining species - referred to as 'others' - are only similar in the first peak, whereas they show a random pattern at larger scales (Fig. 8.3B). We display in Fig. 8.3B and Fig. 8.3D only the species contributions curves of the abundant species, since including the rare ones would have led to scaling problems in the diagrams. The rare species do not markedly contribute to the overall curve anyway, since their contributions to it are weighed by their respective abundances.

In Sandrivier the spatial pattern is a different one: there is no peak found at small scales, but a negative deviation from randomness at the 30-40 cm scale. As in the Tierberg data, there is also a positive deviation at larger scales (Fig. 8.3C), which peaks at 100-120 cm, but unlike Tierberg it decreases again and there is a random pattern again from 160 cm upwards. These trends are similarly found in the curves of individual species contributions (Fig. 8.3D), although there is a greater variability between species at Sandrivier than there is at Tierberg.

8.4 Discussion

8.4.1 Data collection

Methods of point pattern analysis assume that plants are points without spatial extension, treating all individuals equally, regardless of their age and size. This of course is a strong simplification which may create biased results (COX 1987). When we arbitrarily chose 10 cm as the minimum distance between two individuals of the same species we may have caused another bias, treating ramets of the same individual as belonging to different individuals and/or vice versa. This effect is probably strongest in the clonal plant *Ruschia spinosa*. Another critical decision was the classification of shrubs with a height of more than 10 cm as established plants, since the height of newly established plants may differ both between individuals of the same species and between different species. Finally, we were not able to do the mapping for several replicate plots in the available time and we therefore could not test if the detected differences between Tierberg and Sandrivier were statistically significant.

8.4.2 Vegetation pattern

For the Tierberg data the significant positive deviation of overall ΔMCI from randomness at small scale (Fig. 8.3A) is obviously caused by the characteristic aggregation of Karoo shrubs in small clumps. YEATON & ESLER (1990) investigated the mechanisms that are responsible for the formation of these clumps, which are mainly interactions between 'coloniser' and 'successor' species.

The difference between the three most abundant species and the remaining species regarding their contributions to ΔMCI at larger scales (Fig. 8.3B) may be explained by the extremely heterogeneous distribution of the remaining species. The 155 individuals of this group occur mainly at the edge of the plot (Fig. 8.1). Thus individuals of the remaining species are found less frequently in plots around individuals of the three most abundant species, which causes positive contributions of *Galenia fruticosa*, *Osteospermum sinuatum* and *Ruschia spinosa* to ΔMCI. The positive contributions of the remaining species themselves is close to zero because of the rather homogeneous distribution of the three abundant species.

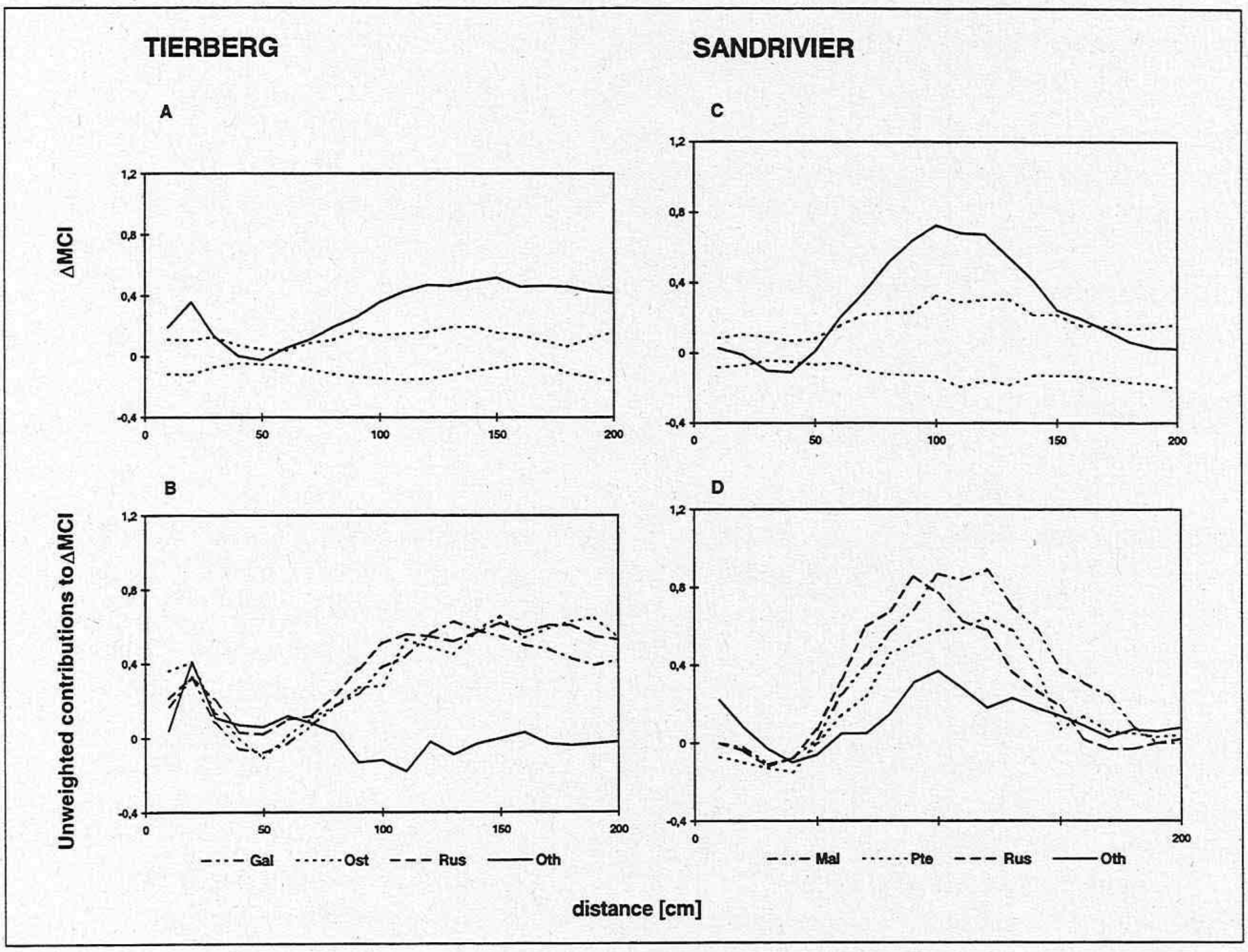


Figure 8.3:
Change in overall deviation (A/C) and species contributions (B/D) to the subcombination case over increasing radius for the Tierberg (protected) and Sandrivier (grazed) data. Confidence envelopes in the upper diagrams were calculated from 19 Monte Carlo randomizations of species distribution. Note that in the lower diagrams the same line type may be a different species. Gal = *Galenia fruticosa*, Ost = *Osteospermum sinuatum,* Rus = *Ruschia spinosa*, Mal = *Malephora lutea*, Pte = *Pteronia pallens*, Oth = other species.

The overall results for Sandrivier differ markedly from those for Tierberg. Instead of a positive one we found a negative deviation of overall ΔMCI from randomness at small scales (Fig. 8.3C). This negative peak might be due to repulsion between certain species. Mechanisms as the dynamics of coloniser and successor plants which lead to small-scale aggregation might be less important at the grazed Sandrivier site. Similarly as for Tierberg, the positive deviation of overall ΔMCI at Sandrivier at scales of 60-170 cm may be explained by the distribution of the remaining species group. However the distribution of this group (Fig. 8.2) seems to be less heterogeneous than at the Tierberg plot. Patches where the remaining species occur appear to be less clearly delimited and more evenly distributed within the Sandrivier plot. This is in accordance with the decreasing values of ΔMCI at scales above 120 cm.

According to PODANI & CZÁRÁN (1997), species with high negative or positive contributions to ΔMCI are key species regarding assembly rules in the community, whereas species with low contributions are less important. In that sense, *Galenia fruticosa*, *Osteospermum sinuatum* and *Ruschia spinosa* can be regarded as important for the large scale community structure at Tierberg, whereas the remaining species group is of lesser importance. At Sandrivier, *Malephora lutea*, *Pteronia pallens* and *Ruschia spinosa* are more important than the remaining species on scales of 50-140 cm (Fig. 8.3D). However, the difference between the curves of the three most abundant species and the one of the remaining species is not as large as for the Tierberg data. In addition, there is a higher variability within the group of most abundant species. *Malephora lutea*, a grazing indicator, shows the highest values of contribution to ΔMCI. The influence of such disturbance indicator species on the vegetation structure is higher at Sandrivier than at Tierberg.

In summary, grazing may have an influence on spatial pattern of Karoo vegetation at both small (<30 cm) and large scales (>150 cm): Firstly, because at both ranges of scale the less disturbed Tierberg vegetation is more heterogeneous than the heavily disturbed Sandrivier vegetation. This could be interpreted as a 'homogenising' effect of grazing on vegetation structure. Secondly, because those species that are favoured by grazing, seem to play a large role in the observed vegetation patterns.

8.4.3 Pattern analysis

The applied technique did detect visible patterns as the small scale clumps of the Tierberg vegetation and it therefore appears to be suitable for the description of spatial vegetation pattern in the Karoo.

The values of ΔMCI indicate whether the compositional information of vegetation in plots of a certain size is higher or lower than expected under random conditions. They do not directly indicate if aggregation or repulsion appears among certain species. Still, the interpretation of ΔMCI values at small and large scales is rather easy, since at small scales under random conditions it is unlikely that several species appear together and a positive deviation thus indicates aggregation. At large scales it is very likely under random conditions that all species appear in the plots. Then a positive deviation means that some species are missing, which can be interpreted as 'repulsion' between the centre species and the missing species.

The interpretation of results for intermediate scales, however, is very difficult. Positive deviations at these scales can be due to repulsion or aggregation among certain species or a combination of these processes. An examination of scattergrams as in Fig. 8.1 and Fig. 8.2

may give a hint of which species are responsible for the deviation, but this approach will remain highly speculative, especially with large plots and insufficient graphical resolution and/or with a large number of species. For a better interpretability of results at intermediate scales it would be necessary to look at the exact observed and expected probabilities of each radius, but this will be literally impossible with species numbers higher than in our study, since with n species there are 2^n possible combinations (PODANI & CZÁRÁN 1997).

The provided information on species contribution does help to find species with high importance for the formation of spatial pattern. No information is provided, though, on how many and which other species are particularly affected by these keystone species. The method might thus be helpful for preliminary investigations of characteristic scales and key species, but it has to be questioned how much this method can contribute to the detection of explicit assembly rules in plant communities.

In order to investigate such assembly rules other methods as the bivariate K-function seem to be more suitable (HARKNESS & ISHAM 1983). The bivariate K-function - or cross-K - does not analyse multi-species pattern but is restricted to the analysis of spatial correlation between two species or guilds. Moreover, it does not use presence/absence data but the actual species abundances within the circular plots, which means that less information is lost.

We will use bivariate RIPLEY'S K-function in a further analysis of our data, where we will investigate whether certain interactions between plants, in particular root competition and coloniser-successor dynamics, have a detectable impact on vegetation structure, and how the processes differ in their relative importance for pattern formation.

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Chapter 9

The influence of vegetation structure and complexity on the distribution of arthropod size classes along a grazing gradient in the Great Karoo

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9.1 Introduction

There are many possibilities to investigate the effect of grazing on plant and animal communities. The part we were interested in was the complexity of vegetation structure, its changes and the effects on the arthropod community along a grazing gradient. We can imagine several direct and indirect effects of grazing on the vegetation, e.g. the changes of the species composition and changes of vegetation structure in the grazed species. The architecture of many plants was shown to be fractal. Thus to characterise the complexity of the plants, we measured the fractal dimension of its structure. Fractal dimension describes the self-similarity of an object in several scales. If, in fractal objects, the unit of measurement is decreased, the surface will increase disproportionately. For that reason, for smaller animals, that inhabit a fractal area, there should be much more space available than for larger ones (MANDELBROT 1982). If the complexity of vegetation is changed by the effects of grazing, there should be alterations in the distribution of arthropod size classes in this area, too. Therefore, we can make two hypotheses to be tested:

(1) Grazing reduces the complexity of vegetation structure.

(2) If vegetation structure is fractal over at least some scales, the complexity differences along the gradient should lead to different distribution of arthropod size classes.

9.2 Methods

9.2.1 Measuring vegetation complexity

For analysing the vegetation structure digital pictures were taken by a Fuji digital camera (Fuji DX-7). In a first attempt we took color photos as a top view from a height of 3.70 m using a ladder. The analysis of these pictures was approached by several image manipulation functions, however, not successfully. There was too little contrast between vegetation and ground. We had to switch to the alternative method of imaging vegetation structure to improve the contrast.

When taking vertical pictures, it is possible to hold a white screen behind the plants as a background, which we did in the second attempt. The white screen was provided with a scale for calibration of the bitmaps. The pictures were taken from a distance of approximately 100 cm and 20 cm above the ground so that the finally analysed pictures contained an area of 50 cm height and approximately 80 cm width. Twenty pictures were taken at the sites B, C, D and E at Sandrivier and at Tierberg, each, i.e. 100 pictures in total (see chapter 1 for information on research sites). The spots for taking the pictures were chosen randomly. By using Micrografx Picture Publisher 3.0, the images were transformed into black-and-white bitmaps (Fig. 9.1).

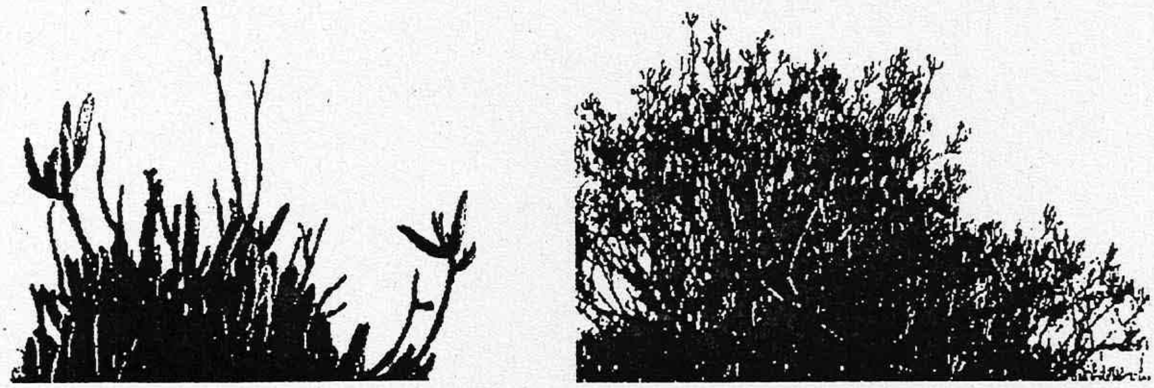


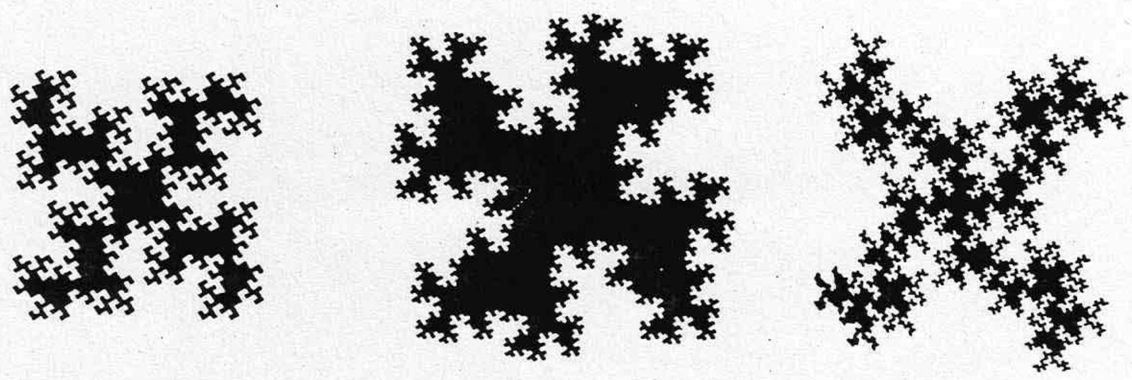
Figure 9.1: Example for black-and-white images for analysis of the vegetation structure.

Analysis of these pictures was carried out with the spatial pattern analysis program FRAGSTATS (McGARICAL & MARKS 1994). This program gives the possibility to calculate a variety of landscape metrics for a landscape consisting of patches belonging to different classes. We examined the landscape on a relatively small scale. In our case the landscape, referred to in the program, is formed by the structures of vegetation. It consists of two classes of patches: vegetation (black) and background (white) (Fig. 9.1). Size, shape and formation of the patches depend on the structure of the plant.

Concerning the scale of classes (i.e. vegetation) we were interested in measuring shape in terms of complexity. As a measurement for complexity we used fractal dimension. Fig. 9.2 gives an example for artificial structures with different fractal dimensions. MANDELBROT (1982) proposed a method to calculate the fractal dimension of natural planar shapes. This perimeter-area method quantifies the degree of complexity in the way that perimeter (P) of a patch is related to the area (A) of the same patch.

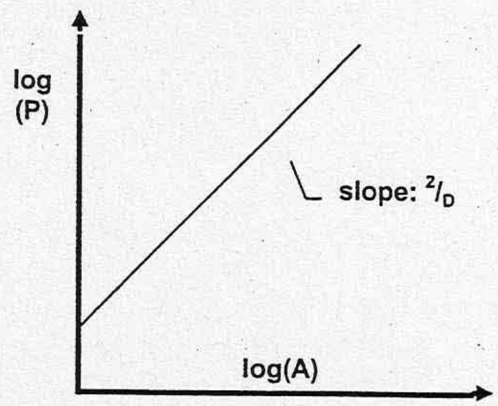
$A = k\,P^{2/D}$ (k is a constant) (BURROUGH 1986)

This index is referred to as <u>double log fractal dimension</u> (DLFD). Perimeter and area are measured for different scales. When log(A) is drawn against log(P) the obtained slope is equal to $^2/_D$ (Fig. 9.3).



D=1.5 D~1.61 D~1.67

Fig. 9.2: KOCH islands with different fractal dimensions (from MANDELBROT 1991).



Relationship between perimeter (P) and area (A) in a fractal structure
when measured on different scales. (D = fractal dimension)

A further measure we compared was a metric to quantify landscape configuration: the contagion index. It measures the intermixing of patches of different classes (interspersion) and the spatial distribution of a patch class (dispersion). A high contagion index is calculated if the patches are well dispersed or if there are only a few large, contiguous patches.

9.2.2 Estimating the distribution of arthropod body length

9.2.2.1 Shrubs

To get an indirect evidence of the grazing effect on the vegetation we tried to measure the body length of arthropods living in shrubs. One single shrub was quickly covered with a plastic bag and cut close to the surface (see Picture 31). The arthropods were killed by BAYER-"Instant knockout" insecticide spray. Two shrub species were examined: *Pteronia pallens* and *Augea capensis*. We did not find enough individuals (3 to 6 per shrub) to continue successfully with this procedure. Otherwise, too many shrubs would have been cut, which is not really effective. Another possibility was to gas the shrubs without cutting and to collect the arthropods from the bottom. Unfortunately this method did not work, because the wind was too strong.

Picture 31: Example of covering of shrubs with a plastic bag for the arthropod analysis ("Sandrivier", March 1998)

9.2.2.2 Pitfall traps

By pitfall trapping we are able to catch arthropods of the epigaeic fauna, those, who are active on the soil surface. We used plastic cups with a diameter of 5 cm as pitfall traps. Nine of them were arranged in a square (three in a line) at each site. We examined four sites (B, C, D, E) at Sandrivier (compare chapter 1 for site descriptions). We filled the pitfall traps with sodium benzoate solution (10%) for conservation. Because of heavy rainfalls that flooded the traps, we only had the capture of four days for our analysis.

Picture 32: Example of pitfall trap ("Sandrivier", March 1998)

9.3 Results

9.3.1 Vegetation complexity

There is a decrease in fractal dimension with increasing distance from the waterhole. (Fig. 9.4) An ANOVA showed this general trend to be significant. Special differences between the sites could only be found between site B at Sandrivier and the site at Tierberg.

A Two-Way-ANOVA should show, whether the difference in fractal dimension of the sites is due to changes in fractal dimension of the plants. Only the pictures with one species were used for this analysis. The result showed that there are no differences between the sites concerning the plants. But there is significant difference between fractal dimension of the species on 5% level (Fig 9.5).

There was no difference in contagion of the images among the five sites (Fig. 9.6).

9.3.2 Arthropod body length

In four sites (B, C, D, E), altogether we captured 1637 individuals during a period of four days. We divided them into seven size classes from smaller than one millimetre (size class 0) up to larger than 25 mm (size class 6; compare Tab. 9.1). Since the used filters were too coarse, no quantitative record was possible in size class 0. Thus, we did not consider this smallest size class, which mainly consists of Collembola and Thysanura.

Table 9.1 shows the range of the size classes, the number of captured inividuals at the different sites and their percentage.

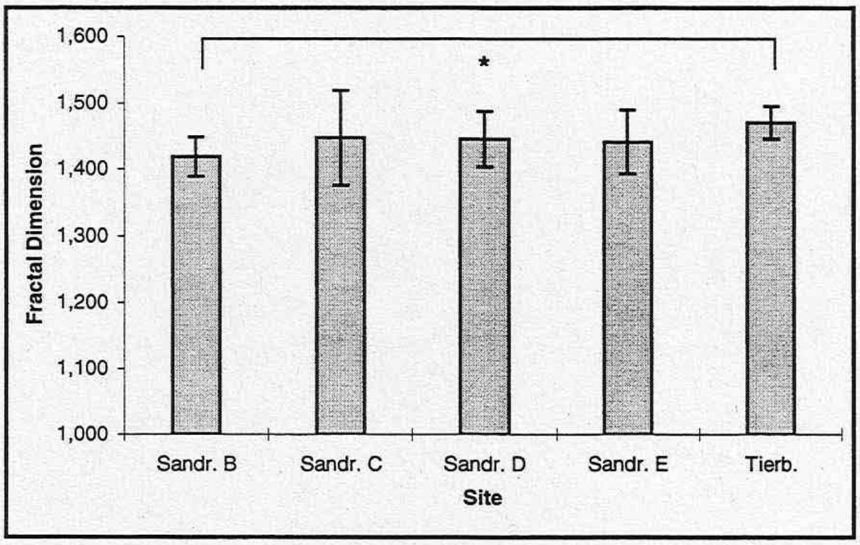


Figure 9.4: Fractal dimension of the vegetation with standard deviation at sites with increasing distance from a waterhole (Sandrivier B-E) and on an ungrazed study site (Tierberg). (The star indicates significant difference on 5% level between the two columns marked by brackets.)

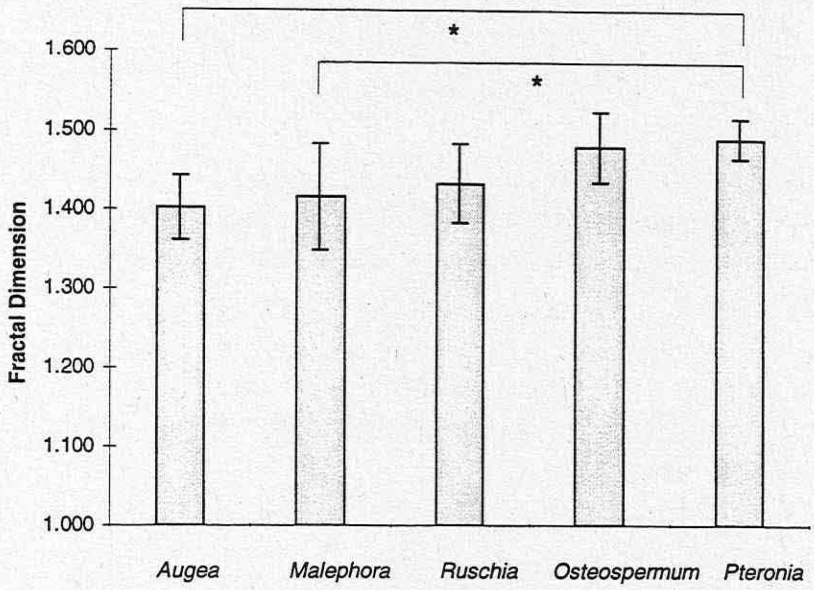


Figure 9.5: Fractal dimension of the five most common species in our samples from all sites with standard deviation. (The stars indicate significant differences on 5% level between the columns marked by brackets.)

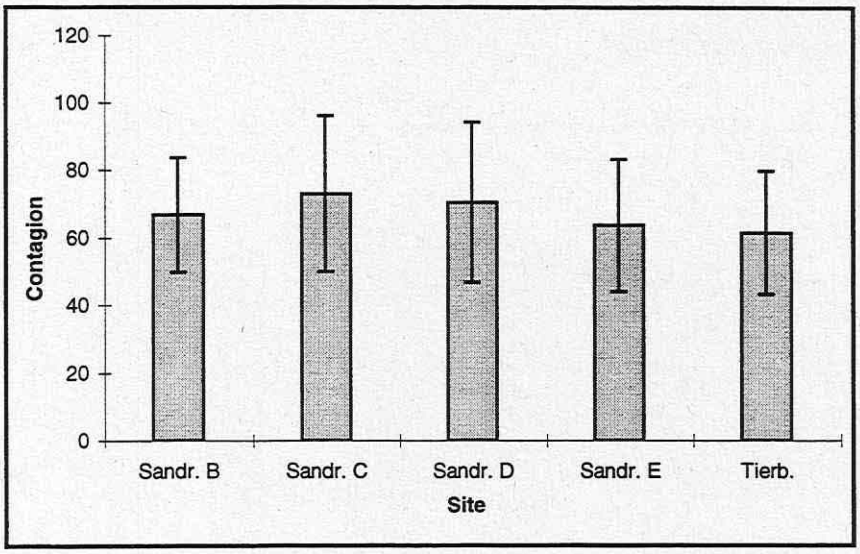


Figure 9.6: Contagion of images of vegetation with standard deviation with increasing distance from a waterhole (Sandrivier B-E) and on an ungrazed study site (Tierberg). (No significant differences.)

As shown in Fig. 9.7, in each site the largest share of arthropods belongs to size class 1. It was mainly composed of several ant species.

To test the significance of the differences in our data, we calculated the linear regression of the common-log-transformed individual numbers as a function of the common-log-transformed size. Table 9.2 presents the results of the statistical analysis. The difference between the size classes in each site (B: $p=0.005$; C and D: $p=0.009$) except of site E ($p=0.102$) are significant.

Table 9.1: Arthropod size classes, the number of captured individuals, and their percentage.

size class	> mm	site B	site C	site D	site E	site B	site C	site D	site E
1	1	442	336	210	228	76%	79%	72%	67%
2	2.5	89	54	44	57	15%	13%	15%	17%
3	5	25	12	12	30	4%	3%	4%	9%
4	10	8	6	7	1	1%	1%	2%	0%
5	15	7	11	9	7	1%	3%	3%	2%
6	25	11	6	8	17	2%	1%	3%	5%

Table 9.2: Arthropod size classes distribution quantified by linear regression of the common-log-transformed individual numbers as a function of the common-log-transformed size.

site	regression slope	standard deviation	t-value	p-value	R square
B	-1.284	0.231	-5.553	0.005	0.885
C	-1.219	0.253	-4.821	0.009	0.853
D	-1.033	0.218	-4.746	0.009	0.849
E	-1.130	0.534	-2.117	0.102	0.528

With the results of the linear regression we compared every site with each other by a variance ratio test (ZAR 1984). In case of equal variances we continued with the exact comparison by t-test (SACHS 1992). If the variances were unequal, an approximate test (SACHS 1992) was used. The expection that the distribution of size classes differs significantly along the gradient could not be validated as shown in table 9.3.

Table 9.3: Comparison of the arthropod size classes distribution by regression coefficients of linear regression of the common-log-transformed individual numbers as a function of the common-log-transformed size class.

sites compared	variance ratio	test	t-value	p-value
B vs C	1.195	exact	0.189	0.854
B vs D	1.130	exact	0.789	0.453
B vs E	5.312	approx.	0.265	0.816
C vs D	1.350	exact	0.557	0.593
C vs E	4.447	approx.	0.151	0.894
D vs E	6.005	approx.	0.168	0.877

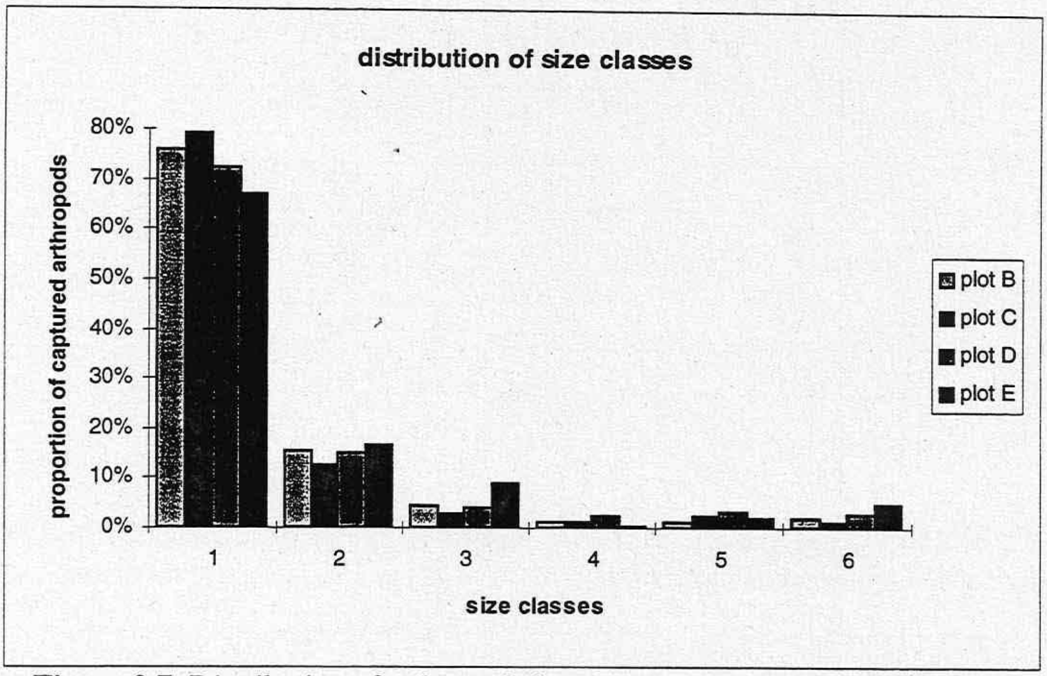


Figure 9.7: Distribution of arthropod size classes (plot = site at Sandrivier).

9.4 Discussion

There is the trend that fractal dimension of the vegetation is decreasing with increasing distance from the waterhole. Due to enormous scattering, our data could not verify significant differences between all sites. These differences in fractal dimension can be due to differences in fractal dimension of the plants on different sites or due to different composition of species with different fractal dimensions. Our results indicate that the latter explanation is true. On different sites the fractal dimension of the plants shows no difference, but there are differences in fractal dimension between species. Also, these differences were not significant for all species. The data set was very small. The data were neither normally distributed nor were the variances equal. For further publication, a more robust test like Games-Howell-Method for comparison of means (SACHS 1990) should be used to test for significant differences.

The contagion as a measure for the structure of the distribution of the vegetation on the image was variable even within the sites. This distribution depends very much on the arrangement of plants, i.e. vegetation patches on the picture. If there is the same probability at all sites that the picture is taken of one large plant in the middle or two large plants at the edges, this has an impact on the contagion index.

Similar to the results of the vegetation structure analysis the distribution of arthropod body lengths is not significantly different along the gradient. But in contrast to these results, we could not even point out a trend. Probably, our sample size was too small and the sampling time too short to support our second hypothesis. As expected, we found the differences in numbers between the size classes within each site to be significant. Deviations from supposed allometrics can be explained by the large amount of ants that provide the main portion of size class 2. Generally, one has to consider the fact that we just captured the epigeic active arthropods and not those living on plants. Thus, there is no direct interaction between the investigated plants and arthropods. To make future investigations to size classes distribution in relation to vegetation complexity more successful, one necessarily has to consider the epiphytic fauna.

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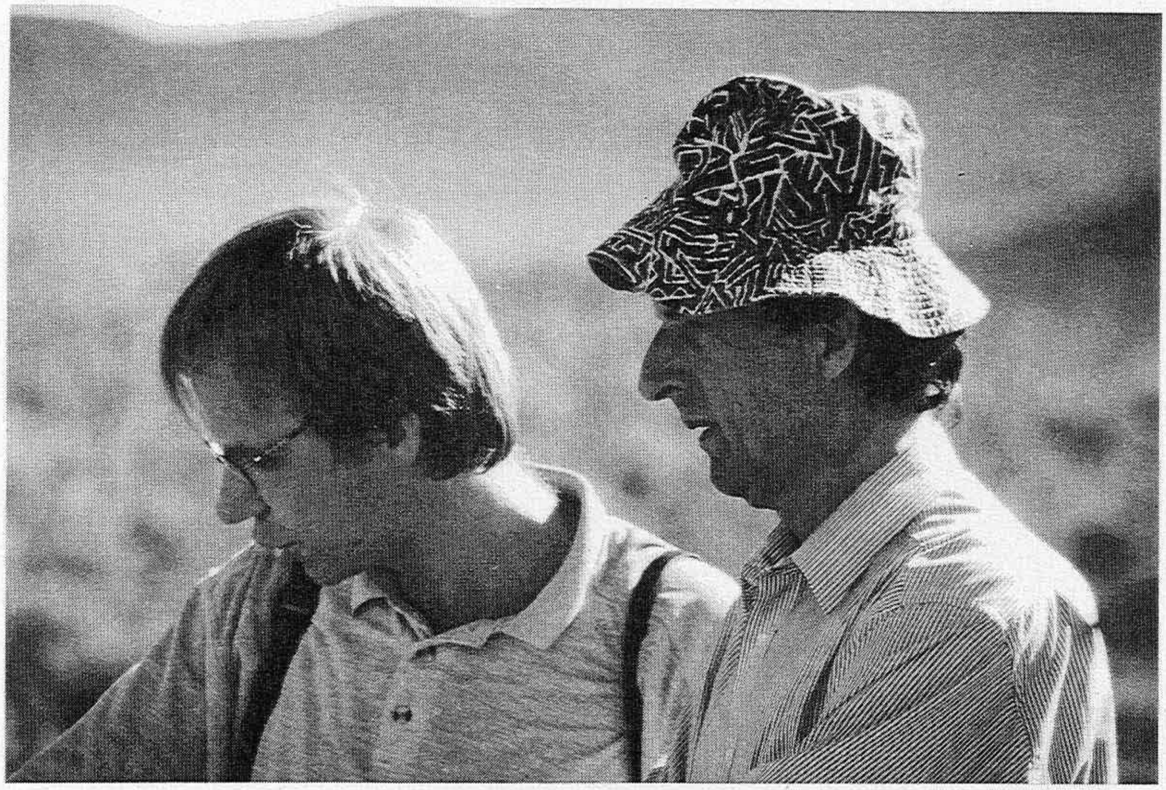
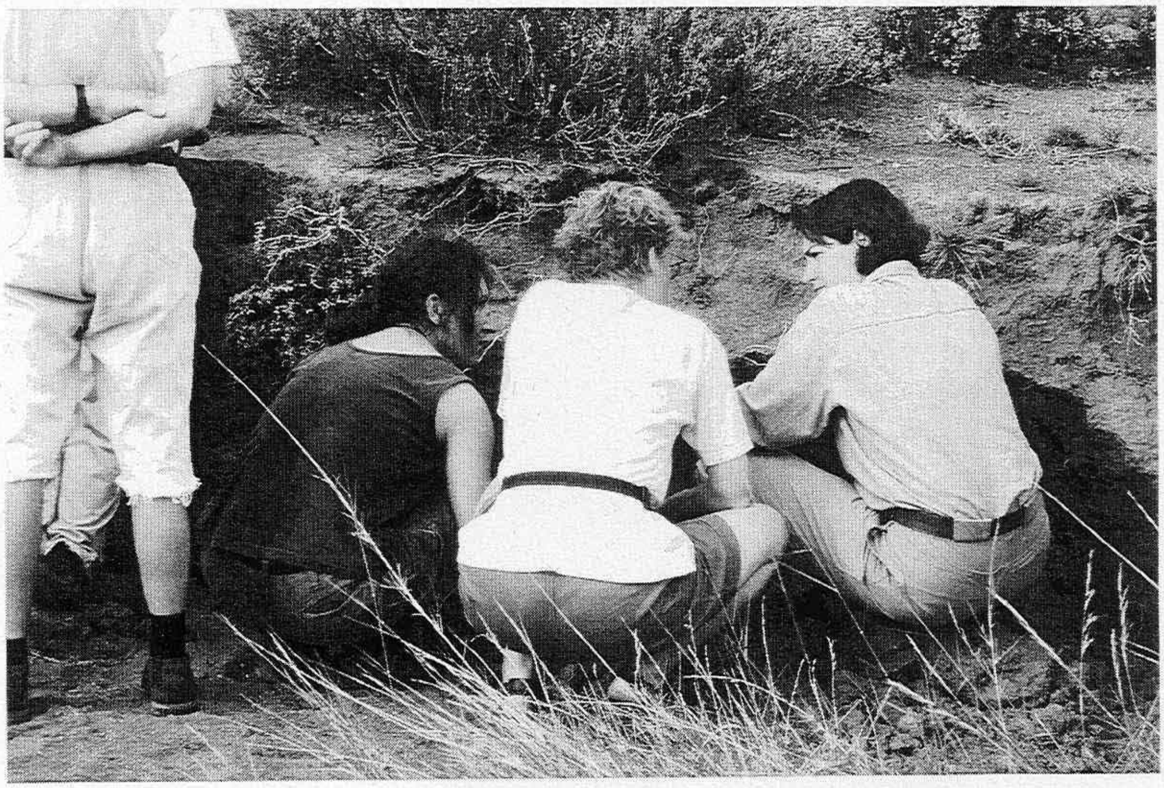
Picture 33:
A tenebrionid beetle; representative of a typical group of desert beetles



Picture 34: ... when theory and application meet...



Picture 35: Interdisciplinary soil profile discussion (near "Tierberg", March 1998)

Chapter 10

Effects of grazing on habitat selection of small mammals in the semi-arid Karoo

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Comment: This contribution has been submitted for publication elsewhere. Thus, within this report only a short abstract is presented. Readers who are interested in further details are herewith kindly asked to get in direct contact with the authors.

Abstract

In this study we tested whether vegetation changes superimposed by grazing affect small mammals, looking at sites with comparable precipitation. We life trapped for small mammals on adjacent grazed and ungrazed farmlands, and chose two habitat types for comparison: plains and drainage lines. Vegetation height and cover, small mammal species composition and abundance were monitored.

Vegetation cover was lower on grazed compared to ungrazed farm land, but vegetation height did not differ. Numbers of captures of small mammal individuals differed greatly in the drainage lines. The ungrazed drainage line was inhabited by nocturnal *Saccostomus campestris* and diurnal *Rhabdomys pumilio*. No animals at all were captured in the drainage line of grazed farmland which seemed to be connected to the lack of bushy plant cover. Numbers of small mammals captured were similar on the plains of both grazed and ungrazed land. Grazed plains though were dominated by one gerbil species, *Gerbillurus paeba*. Ungrazed plains had lesser numbers of *G. paeba* and higher numbers of *Macroscelides proboscideus*. The total number of species captured on grazed plains was higher, but species diversity lower.

Grazing has a different impact on the mammal habitat types of the semi-arid Karoo. Quadrupedal mice like *R. pumilio* and *S. campestris* were only found in the ungrazed drainage line, They depend strongly on vegetation for cover and food, and were absent in grazed drainage lines with low vegetation cover. Plains were inhabited by bipedal small mammals *G. paeba* and *M. proboscideus* that are possibly less susceptible to grazing. Grazed plains differed to ungrazed plains in species diversity but not in abundance of small mammals. No bipedal small mammal species were invading the uninhabitated grazed drainage lines, probably a sign for abundance of small mammals in microhabitats due to habitat preferences or to predation risk encountered, but not due to competition with other species.

Picture 36: Trap for small mammals placed between shrubs
("Tierberg", March/April 1998)

Chapter 11

Information on some butterfly species encountered around Tierberg research station (Prince Albert/South-Africa)

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11.1 Introduction

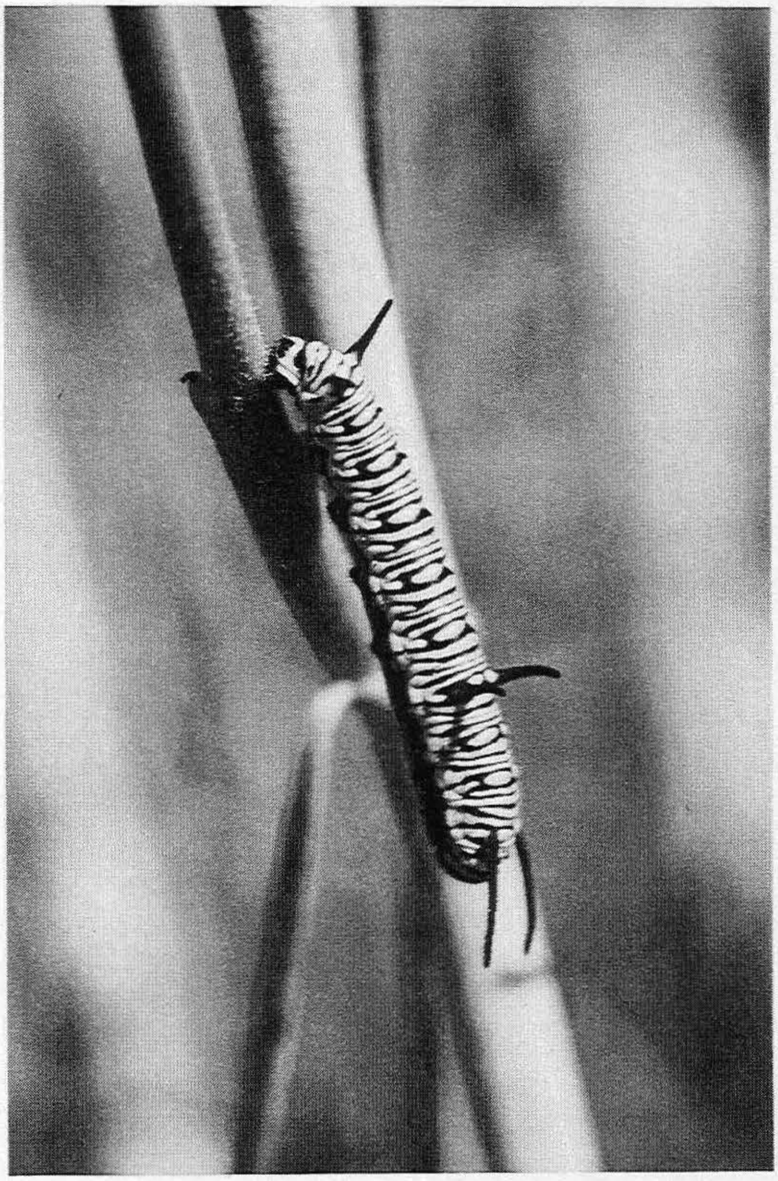
Due to the total lack of information about most invertebrate groups in the area, a small study on the presence of butterflies was conducted during the excursion. Within this chapter the species encountered will be listed and their ecology will briefly be described, based on PRINGLE et al. (1994).

11.2 Species encountered

***Danaus chrysippus* (LINNAEUS)** (Danaidae)

This large Danaid species is very common and occurs nearly all over Africa. It flies throughout the year and at almost all altitudes. Larvae and adults are in general distasteful to predators, as they contain alcaloids. Foodplants are species of *Asclepias*, *Ceropegia*, *Stapelia*, and *Huernia*.

In the study region it was commonly found near to or on *Asclepia* spp.. Nearly all stages (eggs, larvae and adults) have been encountered at the same time (compare caterpillar on Picture 37). One individual of the species was used to show the techniques of marking butterflies with waterproof pens. The specimen obviously left the patch directly after marking with a rather direct flight towards the West, but 4 days later was found again in the place of marking. As Danaids are regarded as strong fliers, one would never have expected such an effect. Maybe it was just a very unlikely event which we happened to witness. However, it could be possible that the species shows some kind of behaviour (e.g. patrolling) which results in some kind of fixed home range. It would be quite interesting to have closer look at the species in terms of dispersal and population structure, although normally such species are believed to be hard to study (which might not be true?).



Picture 37:
The caterpillar of *Danaus chrysippus* on *Asclepia* sp.

***Iolaus bowkeri* (TRIMEN)** (Lycaenidae)

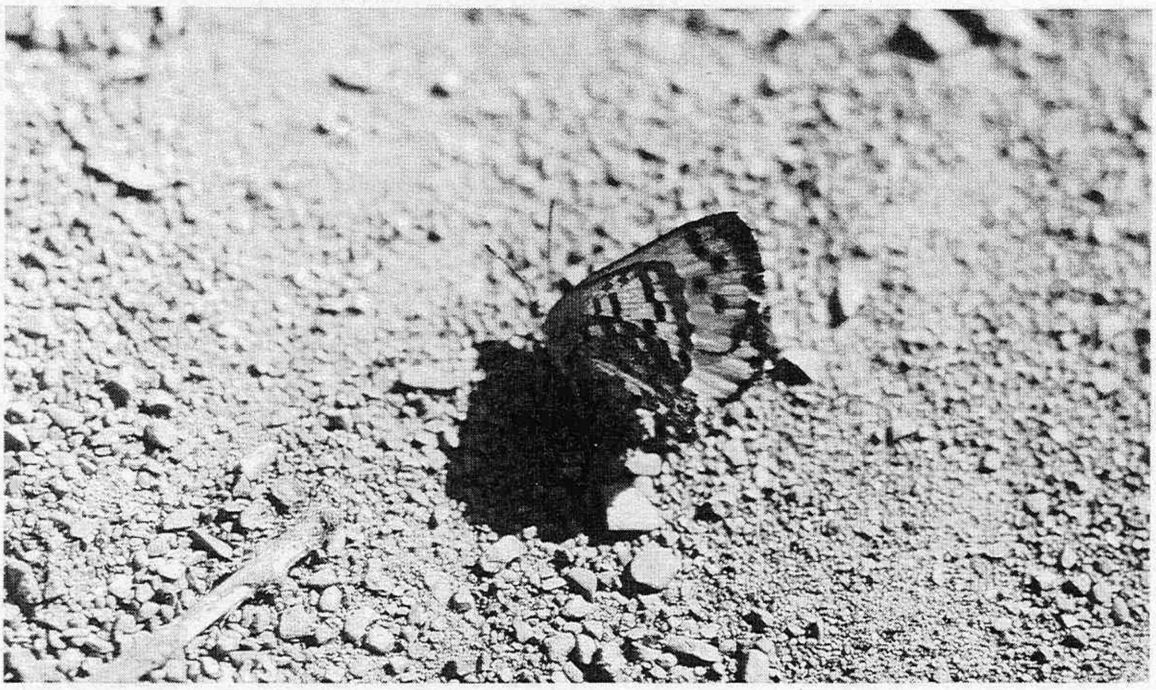
This Thecline butterfly has been encountered as a singleton in a wash of "Argentina" farm (area outside the fences around Tierberg research centre, where also parts of the study of ECCARD & WALTER, see chapter 10, have been conducted). It is to be found nearly everywhere in South Africa where bushveld vegetation grows. The adults often settle on thorny branches. Foodplants of the larvae are *Loranthus elegans* and *L. oleaefolius* (=*Moquiniella rubra* and *Tapinanthus oleifolius*), *Viscum rotundifolium* (Mistletoe), and *Ximenia caffra*.

***Iolaus mimosae* TRIMEN** (Lycaenidae)

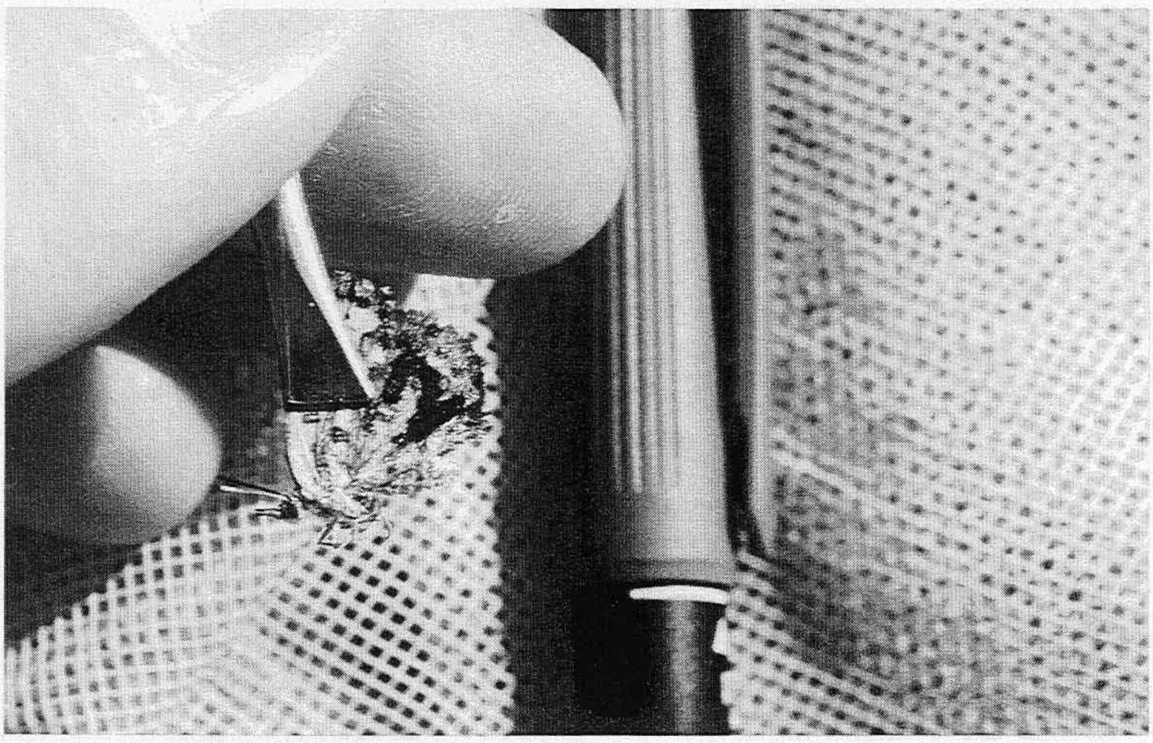
Also this species was found only once in a wash of "Tierberg" research station (see chapter xx for details). It is fond of flying around Acacias and is known from many parts of the Karoo. The species is inclined to sit on twigs well in the middle of a 'thorn tree', which makes the use of a net quite difficult. Larval foodplants are *Loranthus* spp. on Acacias (including *L. elegans* = *Moquiniella rubra*). The animals are easy to breed, as the foodplant lasts well in a closed jar.

Chrysoritis chrysantas **(TRIMEN)** (Lycaenidae)

This species has been found in many individuals on "Tierberg" as well as "Argentina" area (compare Pictures 38 and 39). It is widespread across the eastern and central Karoo to Namaqualand and even farther north. According to PRINGLE et al. (1994) it is seldom seen in large colonies, which seems to contradict the impressions from our field sites. The species is usually seen feeding on Mesembryanthemums on the flats or gentle slopes. It must be approached carefully, as it easily flushes and does not always return to the same flowers.



Picture 38: A resting specimen of *Chrysoritis chrysantas* at Tierberg (March 1998)



Picture 39: For population biological studies butterflies can be individually marked, like shown here with *Chrysoritis chrysantas* ("Tierberg", March 1998)

***Syntacurus cf. pirithous* (LINNAEUS)** (Lycaenidae)

Several specimens have been sighted in different washes of the area. The species is regarded as common in almost every part of South Africa, and it extends northwards through Africa into parts of Europe, and even Asia. It occurs along the edge of thick bush, in the open bushveld, and other types of country. Foodplants are *Plumbago capensis* (= *P. auriculata*), *Indigofera*, *Rynchosia*, *Vigna*, *Burkea*, *Mundulea*, *Melilotus*, and *Crataegus*.

***Harpendyreus tsomo* (TRIMEN) / *H. noquas* (TRIMEN)** (Lycaenidae)

One specimen of a species of the Genus ***Harpendyreus*** has been found in a wash near Tierberg (outside the fenced area). As the species could not be identified, no further details are given here (larval foodplants of *H. tsomo*: *Mentha* sp., and of *H. noquasa*: *Alchemilla capensis*).

***Azanus jesous* (GUÉRIN-MENEVILLE)** (Lycaenidae)

This species has been very abundant in all the washes of the area. It is known to be widely distributed all over South-Africa, „where any wild 'thorn tree' grows. ... It flutters endlessly round the Acacia trees when they are in flower, and is easily caught." (PRINGLE et al. 1994). Foodplants are flowers, buds, and leaves of *Acacia* spp., as well as flowers and buds of *Entada spicata*. Detailed data on the life history are compiled in CLARK & DICKSON (1971).

***Azanus moriqua* (WALLENGREN)** (Lycaenidae)

This species has occasionally been sighted in the washes of the area. It is known to be nearly as widely distributed as the latter species mentioned and has a very similar ecology and behaviour. Foodplants are flowers and buds of *Acacia* spp., including *Acacia karroo*.

***Colias electo* (LINNAEUS)** (Pieridae)

This species according to PRINGLE et al. (1994) is one of the commonest and most widespread butterflies of Southern Africa. It is one of the few butterflies that feeds on some of man's crops (e.g. Lucerne and Clover). During our excursion it has been encountered in the centre of Prince Albert (visiting garden flowers) and along the Swaartberg Pass. Foodplants are *Vicia sativa* (Lucerne), *Trifolium* (Clover), *Robinia pseudoacacia* and other plants.

***Pieris helice* (LINNAEUS)** (Pieridae)

A single specimen has been seen on the "Argentina" farm (see at *Iolaus bowkeri* for information). The species is also regarded as being widely distributed and commen in South Africa. „It seems to prefer the open areas, flutters about old fields in the 'thorn' country and is seen all through the Karroo" (PRINGLE et al. 1994). Foodplants are *Heliophila* spp., *Alyssum* spp. *Lepidum capenses*, *Sisymbrium* spp., and *Reseda odorata*.

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ACKNOWLEDGEMENTS

Research activities of the interdisciplinary group have been supported by many local people and officials. The most important experience has been to live with and among the people of Prince Albert. We herewith want to say 'thanks' to all the ones who so heartily welcomed us, who supported us in our work, who had to suffer from some noisy late night events........

We especially would like to mention

in Prince Albert:

Deon Gouws, Herman Olivier, Clive van Hasselt, Nick and Anna Herbst, Doni Marais, Pat and Helena Marincowitz, Dr. de Merwe, Johann Mynhardt, Theo and Anniki Oosthuizen, Henni du Plessis, Leon de Wit, Piet van Wyk, Pieter Schneekluth, the manager of the tannerie, the staff of the slaughterhouse, the people of the Prince Albert tax and income office, the officers of the police station, the students of the 'disturbance ecology module' of the UCT conservation biology course, all the people in who's houses we so very much enjoyed to stay

in Capetown:
Morne du Plessis, Peter Ryan, and (with very special thanks) **Marie Nelson**

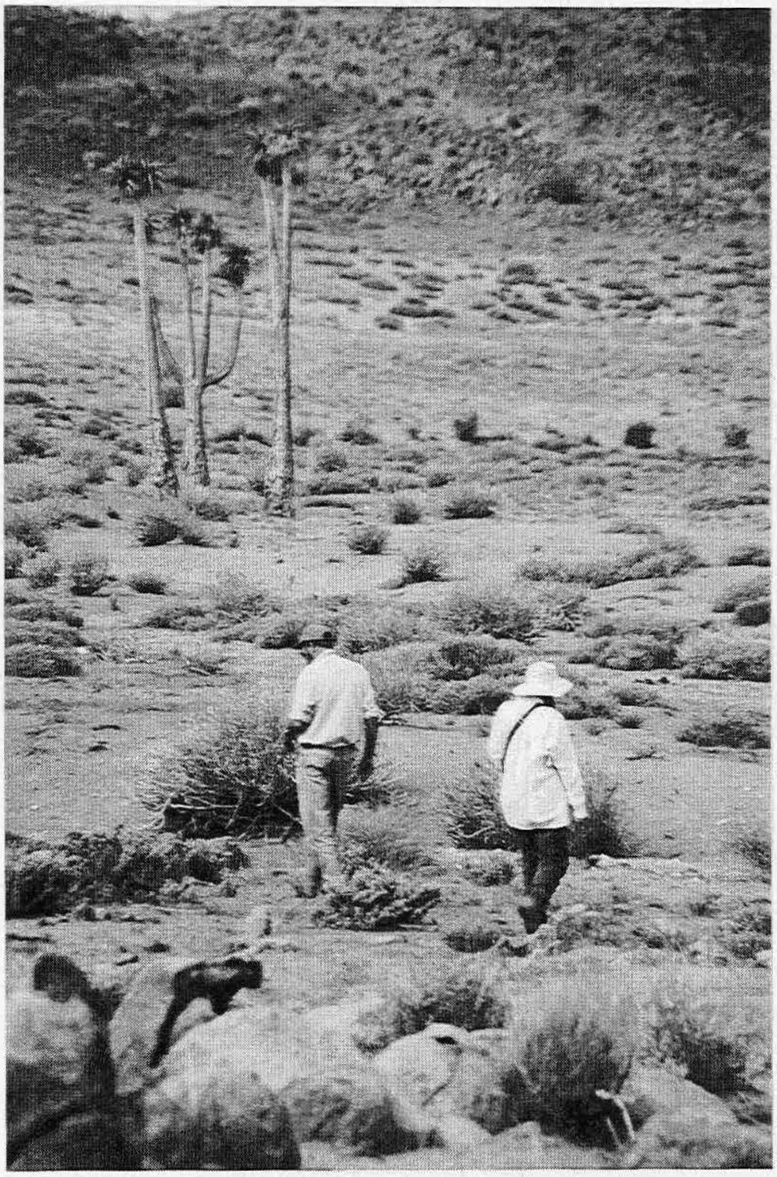
in Germany:
Heinz Borg, Käthe Geyler, Klaus Henle, Florian Jeltsch, Joachim Sauerborn, Christian Wissel, Marlies Uhlig.

We are indebted to the University of Halle and the LAUBAG company for financial support of this excursion.

We ask for apology to the many more people who have been in one or another way involved in the excursion and whom we might have forgotten to mention.

Finally, we thank all the ones, who followed our invitation to the public presentations of our results. This was one of the most important parts of our work, and we hope that for some of the people in Prince Albert or Capetown it was worthwhile attending.

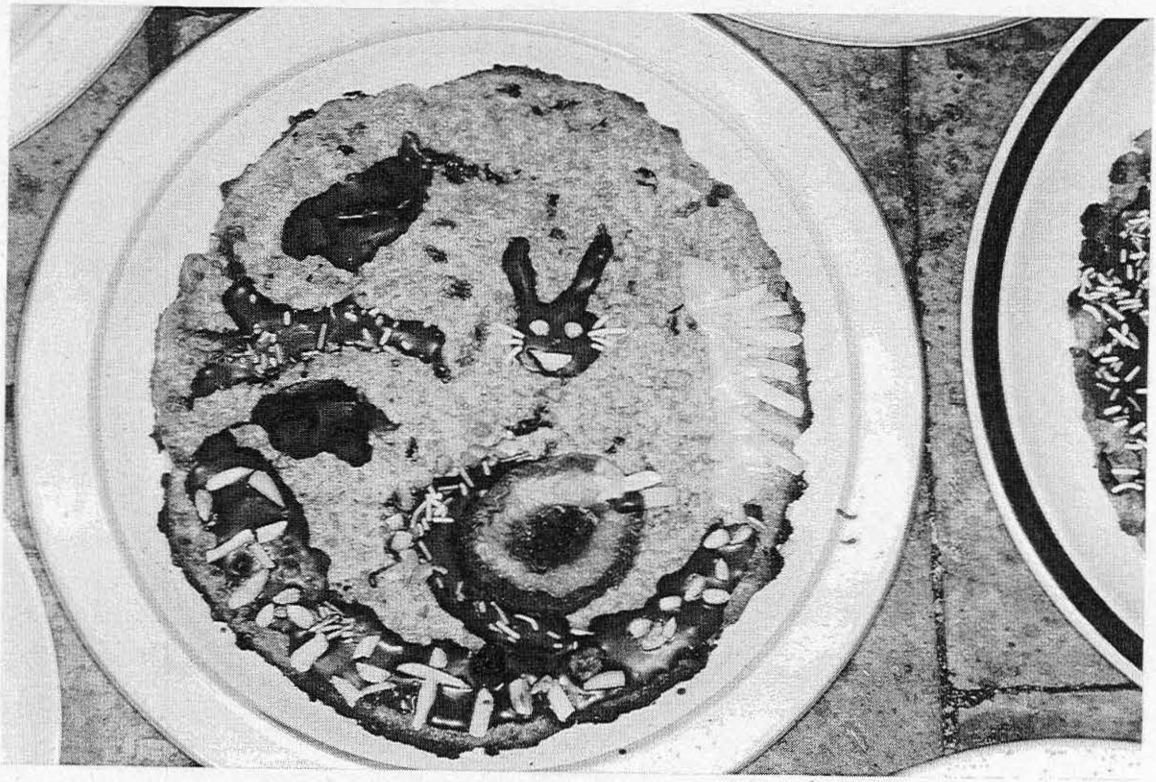
Last, but not least, a very warm 'Thank you' to **Sue Milton** and **Richard Dean** (compare Picture 40), who had so much patience with our crowd and who always have been extremely helpful from the very beginning (planning) of the event up to the very end of it (discussion meeting back in Germany in summer 1998).

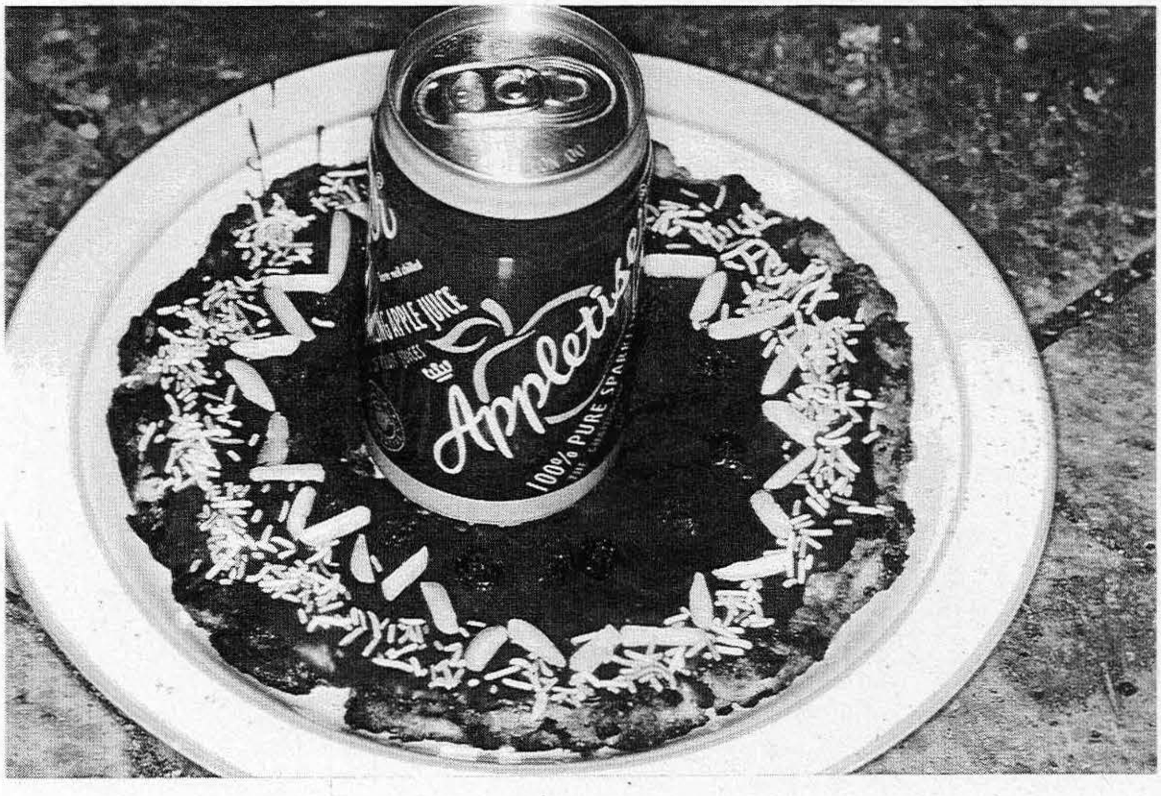


Picture 40: 'Thank you' to Sue MILTON and Richard DEAN (Richtersveld. April 1998)

APPENDIX

Special cakes from special people for special people

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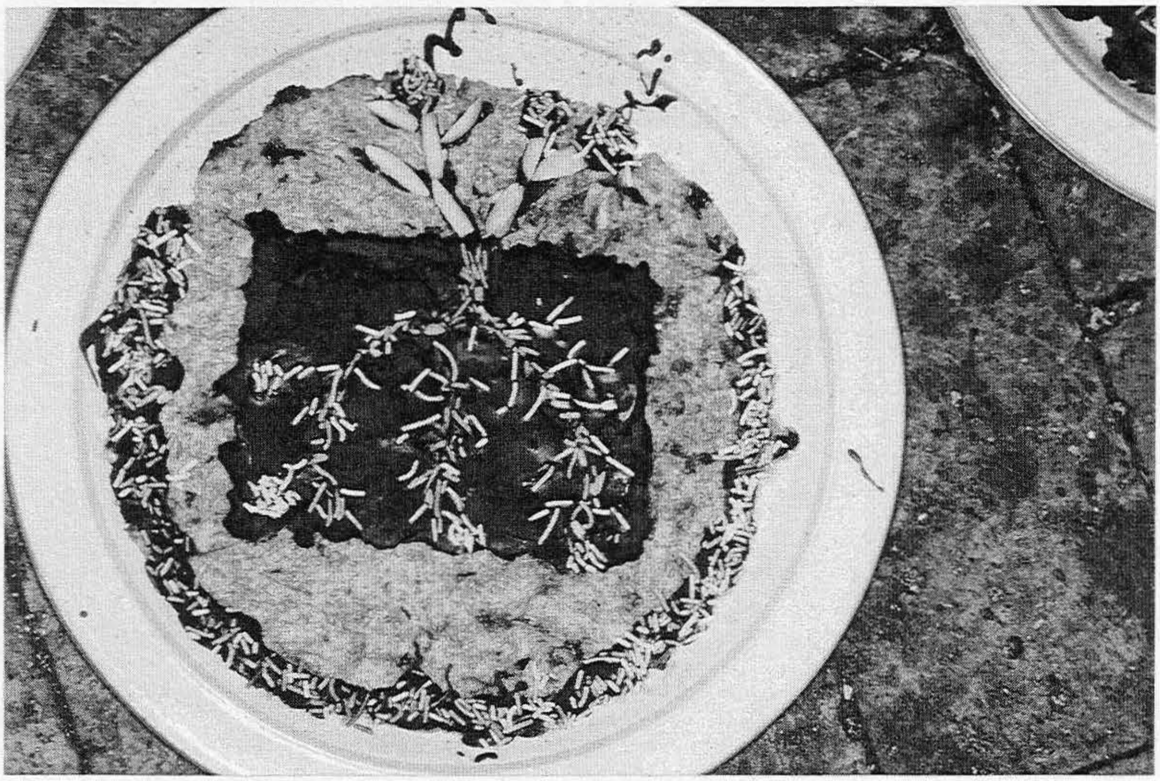

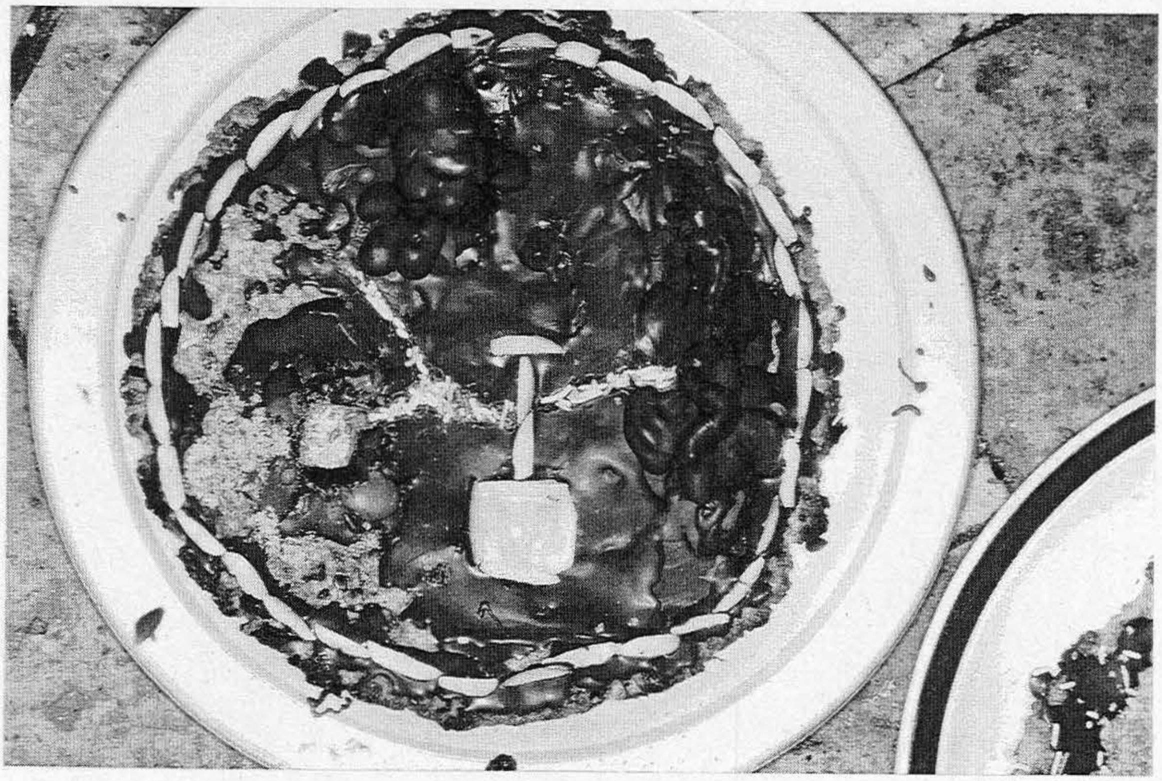

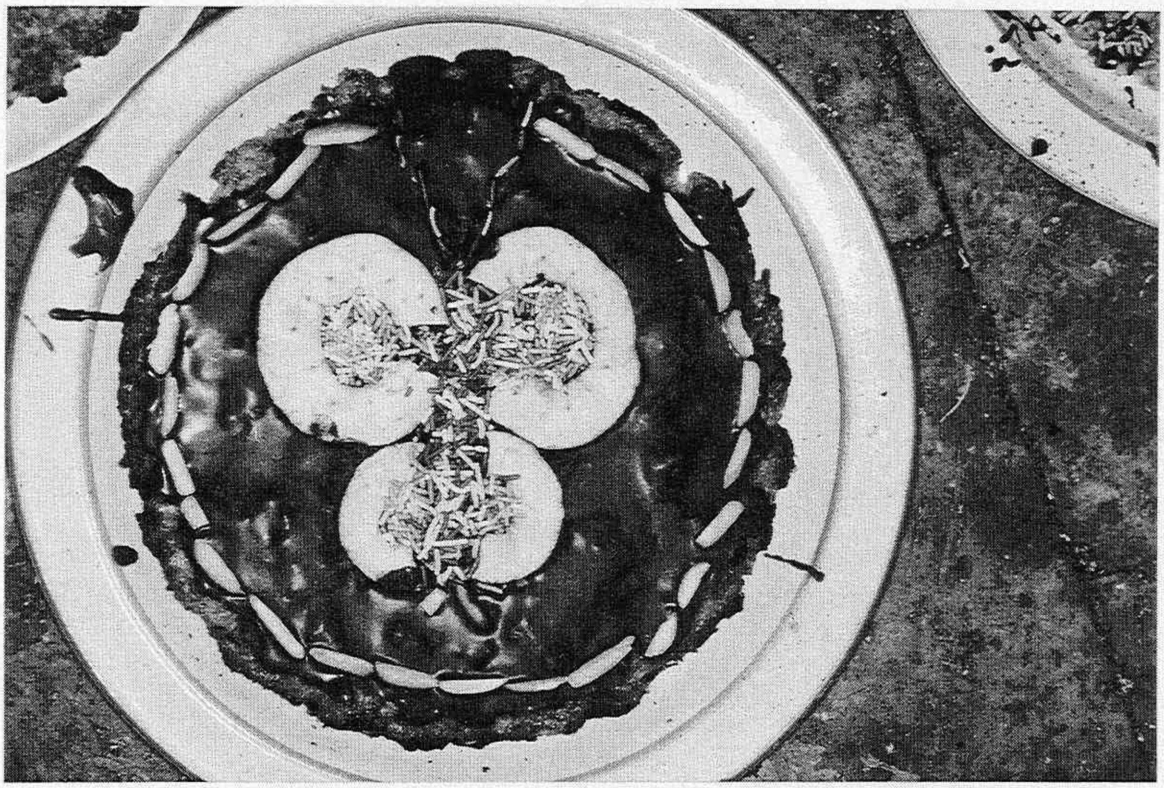

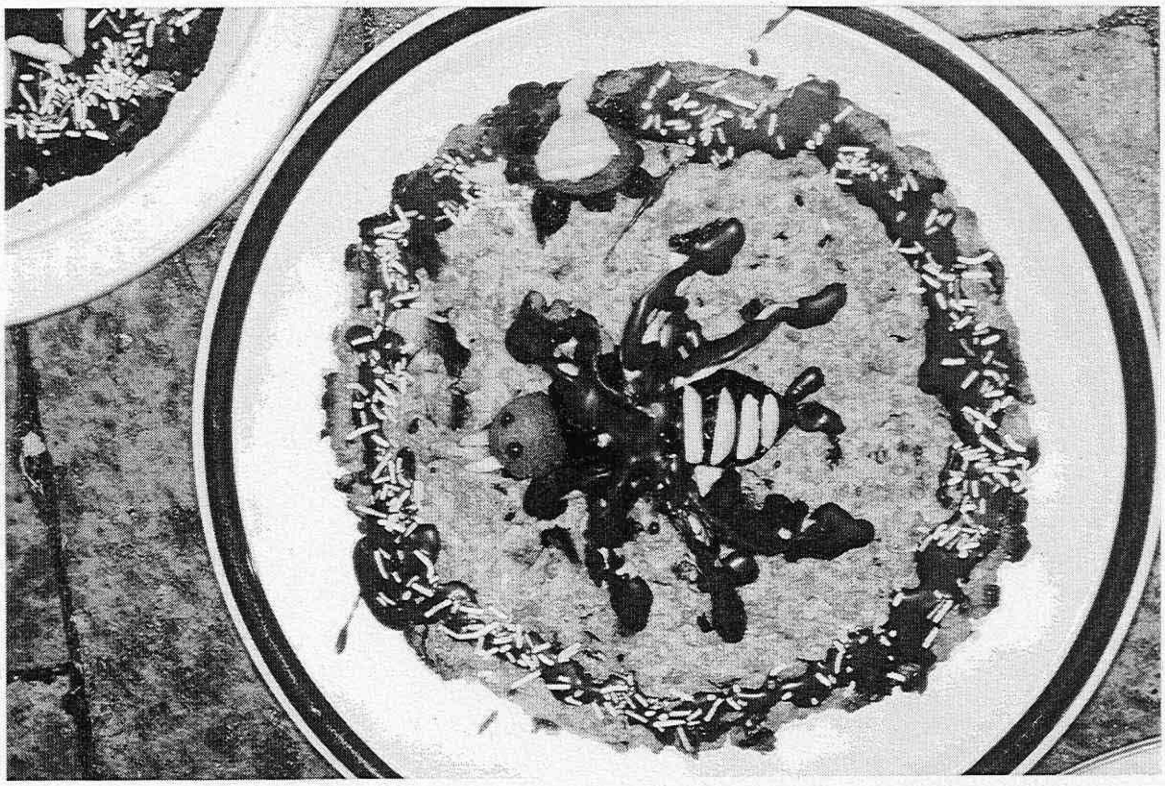

Authors of Pictures:

all pictures by Doris VETTERLEIN & Josef SETTELE

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