Biodiversity in Southern Africa

Vol. 3

Implications for Landuse and Management

SPONSORED BY THE

Federal Ministry of Education and Research

BIOTA

Klaus Hess Publishers
www.k-hess-verlag.de

ISBN all volumes: 978-3-933117-44-1 (Germany), 978-99916-57-30-1 (Namibia)
ISBN this volume: 978-3-933117-47-2 (Germany), 978-99916-57-33-2 (Namibia)

Printed in Germany

Suggestion for citations:

Volume:
Hoffman, M.T., Schmiedel, U., Jürgens, N. (eds.) (2010): Biodiversity in southern Africa **3**: Implications for landuse and management. Göttingen & Windhoek: Klaus Hess Publishers.

Chapter (example):
Schmiedel, U., Linke, T., Christiaan, A.R., Falk, T., Gröngröft, A., Haarmeyer, D.H., Hanke, W., Henstock, R., Hoffman, M.T., Kunz, N., Labitzky, T., Luther-Mosebach, J., Lutsch, N., Meyer, S., Petersen, A., Röwer, I.U., van der Merwe, H., van Rooyen, M.W., Vollan, B., Weber, B. (2010): Environmental and socio-economic patterns and processes in the Succulent Karoo—frame conditions for the management of this biodiversity hotspot. – In: Hoffman, M.T., Schmiedel, U., Jürgens, N. (eds.): Biodiversity in southern Africa **3**: Implications for landuse and management: 109–150. Göttingen & Windhoek: Klaus Hess Publishers.

Subchapter:
If you want to refer to a Subchapter you should insert the citation to the Subchapter as follows (example):
“... see Subchapter by Hanke & Schmiedel on Restoring degraded rangelands in Schmiedel et al. (2010) ....”

Corrections brought to our attention will be published at the following location: http://www.biota-africa.org/biotabook/

Cover photograph: A farmer and a researcher walking and talking in the veld in the northern Succulent Karoo, South Africa.
Photo: Imke Oncken, Hamburg/Germany.
Cover Design: Ria Henning

Article IV.4

– Author's copy –

Please cite this article as follows:

Schmiedel, U., Linke, T., Christiaan, R. A., Falk, T., Gröngröft, A., Haarmeyer, D. H., Hanke, W., Henstock, R., Hoffman, M. T., Kunz, N., Labitzky, T., Luther-Mosebach, J., Lutsch, N., Meyer, S., Petersen, A., Röwer, I. U., van der Merwe, H., van Rooyen, M. W., Vollan, B., Weber, B. (2010): Environmental and socio-economic patterns and processes in the Succulent Karoo - frame conditions for the management of this biodiversity hotspot. – In: Hoffman, M. T., Schmiedel, U., Jürgens, N. [Eds.]: *Biodiversity in southern Africa. Volume 3: Implications for landuse and management*: pp. 109–150, Klaus Hess Publishers, Göttingen & Windhoek.

Succulent Karoo

Flower display on fallow land in Namaqualand. Photo: J. Dengler.

Part IV

IV.4 Environmental and socio-economic patterns and processes in the Succulent Karoo—frame conditions for the management of this biodiversity hotspot

Succulent Karoo

Environmental and socio-economic patterns and processes in the Succulent Karoo—frame conditions for the management of this biodiversity hotspot

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Summary: The Succulent Karoo, the arid winter rainfall area of southern Africa, is one of the most diverse biomes of the region. BIOTA Southern Africa's research activities in the Succulent Karoo Biome focussed on Namaqualand, a 50,000 km^2 region in the western part of the biome. In order to describe the environmental and socio-economic frame conditions of the land management of the Namaqualand, this chapter has been subdivided into six Subchapters.

The introduction (IV.4.1) provides general background information on the natural environment and history of the area and the resulting challenges for the landuse management in Namaqualand. In the subsequent Subchapter (IV.4.2), we describe the BIOTA researchers' findings on soil patterns at different spatial scales, i.e. landscape- (km²), habitat- (hectare) and micro-scales (< 1 m²), and their effect on vegetation patterns and plant species turnover. We discuss the consequences of these findings for land management practices that aim to maintain the unique species richness of the area. We continue (Subchapter IV.4.3) by describing the effect of cultivation on the species richness of annual and perennial plants and species composition of the vegetation. Results showed that over the past 15 years total species richness has increased with time since abandonment at all monitoring sites. Species composition of the perennial species showed a clear directional trend over the monitored years, whereas annual species composition was dictated by the timing and the amount of rainfall in a growing season. The findings have consequences for the restoration of old lands but also for their management for the best flowering display to attract tourists. The best flowering displays were associated with the old fields that were tilled approximately every four years.

In order to restore disturbed and transformed ecosystems within a practical time scale, BIOTA implemented and tested active restoration measures (i.e. brushpacks, dung, microcatchment, functional plant transplants, stone cover), in four major ecological regions of Namaqualand (i.e. Richtersveld, Coastal plain, Namakwaland Klipkoppe, Knersvlakte). The results are compared and the underlying processes that influence critical factors like soil hydrology, chemical soil properties, life history traits of plants, and plant interactions, are discussed in the context of ecological dynamics as well as implications for restoration practices (Subchapter IV.4.4).

Based on our interdisciplinary insight into the socio-economic environment of the Soebatsfontein settlement and its new commonage, in the second last Subchapter (IV.4.5) we describe the challenging and facilitating frame conditions for sustainable land management in that community. The study provided some practical recommendations but also revealed that successful implementation of the recommendations would require an integrative process comprising a broad range of local stakeholders.

Finally, we conclude (Subchapter IV.4.6) that land management recommendations alone are not sufficient to help the small-scale farming communities like Soebatsfontein to improve their livelihood and to make their farm management practices more sustainable. Beyond sound recommendations, other support is needed. Among these are transdisciplinary, participatory action research that aims to solve the socio-economic challenges of the community, access to more farmland for poor farming communities and in the long-run, more capacity development in order to reach more diverse livelihood options.

4.1 Introduction

[M.T. Hoffman & U. Schmiedel]

Photo 1: The mountainous granite-derived Kamiesberg uplands are characterised by narrow valleys, which, in the communal areas, are frequently occupied by individual stockposts such as in this photograph taken near Garies. Photo: Timm Hoffman.

Photo 2: An example of the gently rolling hills characteristic of the sandy coastal plain with the foothills of the granite-derived Kamiesberg uplands in the distance. Photo: Pippin Anderson.

The Succulent Karoo Biome covers a wide geographic range extending from southern Namibia in the north into the intermontane valleys of the Little Karoo in the south (Mucina et al. 2006). The focus of this chapter, however, is only on a portion of the Succulent Karoo Biome called Namaqualand (Cowling & Pierce 1999), where the BIOTA Observatories are located and where the work of several BIOTA researchers has been concentrated. Namaqualand itself is about 50,000 km^2 in extent and comprises about a quarter of the Succulent Karoo Biome. It is located in the extreme northwestern part of South Africa and is quite unique in the southern African context. It is bounded in the north by the Gariep River and in the south by the Olifants River and incorporates several distinct bioregions (Desmet 2007). These include the Knersvlakte in the south, the Kamiesberg Mountains in the central parts, and the Richtersveld in the north, with the coastal plain and Bushmanland bordering the region in the west and east respectively.

Namaqualand supports a varied topography with elevations up to 1,700 m in places. This topography is underlain by a relatively complex geology, which can change rapidly over short distances. For example, ancient igneous sediments of the Kamiesberg Mountains (Photos 1 & 2) are juxtaposed with the more recent marine-derived sands of the coastal plains in the west, the Kalahari sediments of Bushmanland in the east and the complex assemblage of metamorphic rocks of the Richtersveld to the north. The unique and eroded quartz-dominated basin of the Knersvlakte (Photo 3), which is situated south of the Kamiesberg, abuts the dolerite escarpment to the west while the sandstone mountains of the Cape Supergroup sediments occur further to the south. This geological complexity has resulted in a diversity of soil textures, depths, and salinity contents (Francis et al. 2007), which is quite unlike any other region explored along the BIOTA South transect (Petersen et al. 2010, Article III.3.3) and is thought to have an important influence on the biotic diversity of the region (Desmet 2007, Article III.3.8, see also Subchapter IV.4.2). Additional influences from burrowing animals and especially from termites adds to this pedological diversity. These termite mounds or 'heuweltijes' are a distinctive feature of the Succulent Karoo Biome landscape and support a distinctive flora thus adding to the diversity of the region (Esler & Cowling 1995, Rahlao et al. 2008).

The climate regime in Namaqualand is decidedly less complex and although annual rainfall can vary from less than 50 mm in the Richtersveld to more than 300 mm in the Kamiesberg uplands it

Photo 3: The plains of the southern Knersvlakte, seen from the escarpment in the east. The famous quartz fields of the Knersvlakte are situated further to the north and west and not visible on this picture. Photo: Ute Schmiedel.

falls largely in the winter months from May to September particularly in the west. The variability in annual rainfall, as determined by the coefficient of variation (CV), is also low (CV < 35%) compared to most other parts of southern Africa where summer rainfall regimes predominate. Temperatures in Namaqualand are also relatively benign (average summer maximum temperature of < 30ºC, Desmet 2007) compared to many other deserts of the world.

This combination of high soil variability together with the relatively predictable winter rainfall and benign temperature regime is thought to be the reason for the high biotic diversity in the region. Namaqualand is promoted as the 'richest desert in the world' (Myers 2003) and contains exceptional levels of diversity and endemism within a number of plant, insect, and reptile families. Furthermore, radiation within some groups, such as the largely succulent plant family, the Aizoaceae, has occurred relatively recently (i.e. in the last 5 million years) and is coincident with the onset of the winter rainfall regime in southern Africa (Klak et al. 2004). This diversity is not uniformly distributed across Namaqualand, however, and appears concentrated in regional centres, often associated with quartzite mountain complexes or quartz pebble, lag-gravel plains such as the Knersvlakte (Desmet 2007). While there have been some recent advances in our understanding of the exceptional diversity of this region much remains to be learnt, particularly the role that quartz environments might have played in promoting the recent diversification of succulent plant lineages. Our basic understanding of insect diversification in the region is also in its infancy.

The archaeological and pre-colonial history of human occupation of the region is equally interesting and quite unique to southern Africa. Although Namaqualand supports a relatively small population of only about 60,000 people, today the region has been occupied by humans for millennia. Archaeological (Webley 2007) and historical (Raper & Boucher 1988) evidence of modern humans who lived a hunter-gatherer lifestyle is found throughout Namaqualand and attests to the long history of people in the region which continued into the early colonial period. However, a fundamental shift in landuse practices occurred about 2,000 years B.P. when Khoekhoen pastoralists are thought to have entered the region from the north. Small groups of Nama-speaking herders of perhaps a few thousand individuals were still present in Namaqualand when early European travellers to the region encountered them settled amongst the western foothills of the Kamiesberg in the late 17th century (Valentyn 1971). They were highly mobile in the landscape and traversed large areas with their herds (Webley 2007). However, a series of smallpox epidemics, which spread from European settlements in the Cape during the 18th century decimated the populations of indigenous people in the region who also lost much of their wealth to the combined impact of cattle and land dispossession. Settler expansion from the late 18th century brought agriculture to Namaqualand and soils were cultivated for subsistence grain production for the first time (Hoffman & Rohde 2007).

Fearing complete dispossession of their land by European settler farmers, Nama-speaking pastoralists approached the church for protection in the early 19th century and secured a number of key pastoral areas for their exclusive use. These relatively large tracts of land form the basis for the communal areas of Namaqualand today (Rohde & Hoffman 2008) which in 2001 comprised about 37% of the area of Namaqualand (Desmet 2007). They have been added to considerably under the South African government's post-1994 land reform programme (May & Lahiff 2007) and have recently been incorporated into the local municipality's governance structures which are today responsible for the management and well-being of people who live in these areas (see also Subchapter IV.4.5).

Despite these recent additions to the land holdings of communal area farmers as well as the improvement in village infrastructure (e.g. through the installation of electricity, water and sanitation) unemployment and consequently, poverty levels, remain high (Rohde et al. 2003). This has not been helped by the recent collapse of the mining sector in the region. While the substantial increase in welfare grants from the state over the last 10 years has helped to support the region's poorest inhabitants there are a number of key challenges for the region today which are centred on improving the well-being of a large number of previously-marginalised people living primarily in the communal areas of Namaqualand. Interventions, which facilitate greater access to land for interested farmers and which expand people's livelihood opportunities beyond agriculture are needed. Although the conservation sector holds some promise in this regard (James et al. 2007) the region is far from the major tourist centres of southern Africa and sustainable job opportunities in conservation will take some time to develop.

Furthermore, it is likely that most of the land in Namaqualand will continue to be used for small stock production for several decades. It is here that the greatest challenge for the region lies. A fundamental question faced by those who use the land is how to improve economic opportunities for livestock farmers without compromising the natural ecosystems and the services they provide in the process (see for instance Article III.5.7). Several studies have shown that high stocking rates transform the lowland environments in particular, which change from a diverse mix of palatable and semi-palatable, perennial shrubs to a relatively uniform mix of unpalatable perennial shrubs and annual herbaceous species, which erupt in abundance in good rainfall years but which remain largely dormant under drought conditions (Anderson & Hoffman 2007, Todd & Hoffman 1999, 2009). This has significant implications for the livestock industry, particularly for resource-poor farmers who are unable to purchase emergency fodder to sustain their animals over the drought period. Understanding how best to manage rangelands given the diverse tenure regimes and biological environments of Namaqualand remains a key challenge for researchers in the region. Increasing mobility is one option (Cousins et al. 2007, Samuels et al. 2008) although changes in this regard remain to be implemented. In addition, many local environments have already been transformed and rangeland restoration has become increasingly important in recent years (e.g. Gabriels et al. 2003, Simons & Allsopp 2007, Subchapter IV.4.4) although the financial and logistic costs need to be properly evaluated. Finally, it has been predicted that of all the environments in southern Africa it will be the Namaqualand environment that will be most affected by the impact of climate change in the 21st century (Midgley & Thuiller 2007, Article III.3.1). Therefore, understanding the basic biology of the region in response to climate change, as well as the critical management problems faced by landusers requires on-going investigation.

Photo 4: The spectacular flower display of the Namaqualand attracts many tourists every year. The photo shows a site near Kamieskroon in the year 2006. Photo: Ute Schmiedel.

In the following subchapters, we outline the findings of ecological and socio-economic research activities within BIOTA in the Namaqualand region of the Succulent Karoo that are critical for land management decisions. In Subchapter IV.4.2 we describe the role of the soil patterns in the Succulent Karoo as drivers for the plant diversity at different spatial scales. The understanding and protection of the resulting spatial heterogeneity is one important criterion for land management that aims to maintain the exceptionally high species richness in the landscape. Disruptive landuse practices such as repeated ploughing has a homogenising effect on the soils. Subchapter IV.4.3 shows that it takes more than eight decades for the vegetation of old fields to recover and to reach a composition of species and plant life forms that is similar to the pre-ploughing condition. Old lands, however, contribute to the attractiveness of Namaqualand for tourists, by supporting a spectacular display of mass-flowering annuals during springtime (Photo 4), which attracts thousands of tourists to the area every year. The economic potential of the landscape and the spring display for the small rural settlements has not been fully explored and may provide one of the options for alternative livelihoods. In order to manage and maintain the flower display at sites and to restore the natural vegetation of the old lands at others, the successional trajectories and the processes behind them need to be understood. Processes that support or hamper the restoration of rangelands that have been transformed through overgrazing, trampling, or mechanical disturbance of soil structure by ploughing or infrastructure installation are described and discussed in Subchapter IV.4.4. Insights into ecological processes that drive the succession of disturbed lands as provided by the Subchapters IV.4.3 and IV.4.4 are important for future management decisions and for the successful restoration of transformed rangelands. This kind of information is required by the local landusers and conservationists.

The challenges that managers of communal lands in Namaqualand have to face

Photo 5: Heuweltjies in the landscape near Soebatsfontein. Photo: Jürgen Deckert.

are described in Subchapter IV.4.5 by using the example of the Soebatsfontein community in the Lowland Succulent Karoo. Over nine years, BIOTA researchers worked closely with members of the Soebatsfontein community and on the communal lands, in order to better understand the ecosystems, their processes and dynamics, the ecosystem services that they provide as well as the frame conditions for management decisions. In Subchapter IV.4.5 we summarise our interdisciplinary findings and discuss the emerging consequences for landuse management.

Finally, we summarise the conclusions resulting from our research and suggest future needs for research and for the implementation of sustainable land management practices in the Succulent Karoo.

4.2 Interdependence of soils and vascular plant vegetation in the Succulent Karoo

[U. Schmiedel, N. Lutsch, D.H. Haarmeyer, I.U. Röwer, A. Gröngröft, J. Luther-Mosebach & A. Petersen]

Introduction

The extraordinarily high biodiversity of the Succulent Karoo is the subject of studies from various disciplines and has been ascribed to several environmental drivers. The climatic conditions during the main growing season in winter and spring, which are characterised by mild temperatures and low but highly predictable winter rainfall (Cowling et al. 1999), are often referred to as an important driver of the species richness. Klak et al. (2004) identified the onset of the winter rainfall regime approximately 5 mya as the main trigger of the diversification of the Aizoaceae, one of the most species-rich and dominant plant families in the Succulent Karoo.

Besides climatic factors, geological and soil diversity have often been discussed as other important drivers of species richness at various spatial scales in the Succulent Karoo (Mucina et al. 2006, Desmet 2007, Francis et al. 2007). Based on the interdisciplinary assessment of the nested plots on the BIOTA Observatories (Subchapter II.1.2), BIOTA researchers analysed the interdependence of soils and vegetation patterns in the Succulent Karoo, at the landscape- (km²), habitat- (hectare), and micro-scales (< 1 m²). In this article we summarise our findings regarding the spatial patterns of three characteristic features in the Succulent Karoo landscape, namely heuweltjies (zoogenic earth mounds), quartz fields and biological soil crusts. We discuss how these patterns affect the plant diversity in the landscape and also what role the plants themselves play regarding the maintenance of patchiness in the landscape.

Drivers of vegetation diversity at the landscape scale

The studies along the BIOTA Southern African transect revealed a high heterogeneity of soils in the Succulent Karoo. The variance of soil chemical parameters of the BIOTA Observatories in the Succulent Karoo (i.e. S21–S28; 25 samples per 1 km²) by far exceeded those of any other BIOTA Observatory in southern Africa (Petersen 2008, Article III.3.3). Due to the high diversity of soil features, which has been corroborated by many studies (see Cowling & Hilton-Taylor 1999, Watkeys 1999, Francis et al. 2007), the Succulent Karoo has been identified as a centre of pedodiversity (i.e. centre of soil diversity, Petersen 2008). Within the 15,000 hectare commonage of Soebatsfontein in the Namaqualand lowlands (around the Soebatsfontein Observatory, S22), eight different soil reference groups (according to the World Reference Base for Soil Resources 2006) were identified. This represents 25% of the 32 defined soil reference groups worldwide and 66% of the 12 groups identified for the entire BIOTA Southern Africa transect (Article III.3.3). Geology, topography, and biological activity (e.g. heuweltjies) are the main factors responsible for the high variability in these soils (Francis et al. 2007, Petersen 2008).

This high pedodiversity corresponds well with the very high species richness of vascular plants in the Succulent Karoo (Mucina et al. 2006, Desmet 2007, Article III.3.8). The high diversity of vegetation patterns in the Succulent Karoo are closely related to patterns of soil types. In particular, soil water conditions, salinity, and soil acidity are the main drivers of the distribution of the various vegetation units occurring in the landscape around Soebatsfontein (Part II, Observatory S22; Luther-Mosebach 2009). Plains with deep coarse sandy soils, for instance, provide relatively favourable soil water conditions due to the restricted capillary rise potential that prevents evaporation of soil water stored in deeper soil layers. The *Stipagrostis ciliata-Othonna sedi-*

folia unit that is typical of these sandy soils is dominated by the palatable perennial grass *Stipagrostis ciliata* (Langbeenboesmangras). Another habitat type, which provides relatively favourable soil water conditions occurs between large rocky outcrops, which are typical for the gneissic mountains of Namaqualand. These soils receive additional run-off water from the rock faces and possibly also additional nitrogen provided from nitrogen-fixing cyanobacteria and cyanobacterial lichens covering the rocks (Dojani et al. 2007). These mountains and rocky areas are inhabited by the *Rhus incisa-Rhus undulata* unit, which consists of a very dense cover of tall shrubs and trees (i.e. chamaephytes and phanerophytes), such as *Rhus* species (Taaibos), which are accompanied by various annuals during spring time. Other communities, which are typical of the loamy-sandy soils of the valleys and gentle slopes in the area are often dominated by *Lebeckia multiflora* (Fluitjiesbos) shrubs and are thus part of the *Lebeckia multiflora-Galenia sarcophylla* unit. These plant communities in the low-lying areas are driven by the strong gradients of soil salinity and pH that are typical of the Succulent Karoo (Petersen 2008, Herpel 2008, Labitzky 2009).

Besides topography and geology, the Succulent Karoo possesses additional characteristic features that increase soil heterogeneity. Heuweltjies (Afrikaans: small hills), for instance, are dominant structures (Photo 5) that contribute to the habitat heterogeneity of the landscape forming a mosaic of distinct circular features on slopes and plains. They are fossil termitaria, which form earth mounds 0.5–3.0 m in height and 15–50 m in diameter. They occupy 14–25% of the land surface of the western Succulent Karoo in the south western part of southern Africa (Ellis 2002, Petersen 2008, Picker et al. 2007). The age and origin of heuweltjies remains a matter of contention, although most authors agree that they are fossil termitaria of the species *Microhodotermes viator* (Lovegrove 1991, Picker et al. 2007, Petersen 2008) dating back more than 4,000 years (Moore & Picker 1991) to more than 20,000 years ago (Midgley et al. 2002), and that they

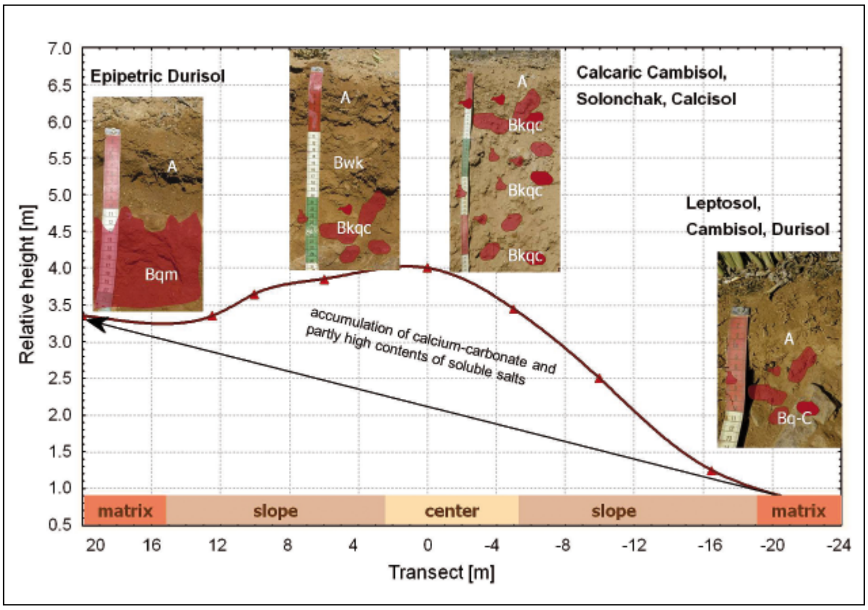


Fig. 1: Schematic representation of the heuweltjie transect in Soebatsfontein showing typical soil units and their position. Durinodes and Duripans are highlighted in reddish colour. (A/B/C represents the main soil horizons, suffix k = accumulation of calcium-carbonates; qc = accumulation of silica concretions; qm = massive duripan).

Table 1: Analyses of a microtransect with five profiles across a heuweltjie structure at the BIOTA Observatory S22 (results are means of all horizons in each profile)

Parameter	Unit	Matrix	Slope	Centre	Slope	Matrix	Median of region
distance	m	18	8	0	–8	–20	
Clay	%	11.7	11.2	9.7	10.8	12.2	n.a.
Silt	%	22.5	27.0	30.1	30.9	17.8	n.a.
Sand	%	65.7	61.8	58.9	58.4	69.7	n.a.
pH ($CaCl_2$)	pH	5.6	7.7	8.1	8.1	5.1	6.0
$CaCO_3$	%	0.0	0.2	1.5	3.2	0.0	< 0.1
EC_e	mS/cm	17.5	7.4	40.0	26.6	1.2	2.3
Ca	g/kg	3.2	5.6	20.7	14.1	3.9	4.5
Mg	g/kg	3.2	6.6	10.3	12.3	2.2	1.7
Crusts	—	Duripan	Durinodes	Durinodes	Durinodes	Duripan	—

may be sustained by rodent burrowing activity. Their old age means that they have persisted through times of fundamental climate change (Turner 2003). Heuweltjies studied at Soebatsfontein (in the surroundings of Observatory S22) by an interdisciplinary team of BIOTA researchers, exhibit high variance in soil properties that change within a distance of less than 10 m (Table 1; for further results see Petersen 2008, Herpel 2008, Röwer 2009).

The physical and chemical soil properties of the heuweltjies enhance small-scale habitat diversity and therefore phytodiversity (Knight et al. 1989, Milton & Dean 1990, Francis et al. 2007). In particular, the accumulation of salts and calcium carbonate generates relatively high pH values in the soil profiles and topsoil horizons of the heuweltjies. Thus, heuweltjies form a pattern of moderately alkaline patches in landscapes with otherwise carbonate free, neutral to moderately acidic soils. Nitrogen and total organic carbon contents were also highest at the centre of these heuweltjies. The reasons for the nutrient enrichment at the centre of

Table 2: Differences in vegetation parameters between heuweltjie zones and other pooled categories (ANOVA)

Zones	Surrounding matrix vegetation zone		Fringe vegetation		Heuweltjie centre vegetation zone			Transformation	
Parameter	Mean	SD	Mean	SD	Mean	SD	*p*	Type	*p*
Soil parameters									
pH	5.97[a]	± 0.85	6.87[b]	± 0.89	8.10[c]	± 0.28	**< 0.001**	Rank	**< 0.001**
EC [µS/cm]	987	± 666	880	± 678	685	± 947	0.392		
$CaCO_3$ [%]	0.04[a]	± 0.05	0.31[a]	± 0.84	3.00[b]	± 2.38	**< 0.001**	Log	**< 0.001**
TOC [%]	0.87[a,b]	± 0.38	0.71[a]	± 0.24	1.06[b]	± 0.51	**< 0.001**	Log	**< 0.001**
N [%]	0.07[a]	± 0.03	0.06[a]	± 0.02	0.10[b]	± 0.03	**< 0.001**		
C/N ratio	13.3[a]	± 1.61	12.2[b]	± 2.75	13.7[a]	± 1.73	**0.002**		
Vegetation parameters									
Species richness [per 100 m^2]	23.7[a]	± 5.97	20.3[b]	± 5.70	15.1[c]	± 6.37	**< 0.001***		
Shannon index	1.702	± 0.514	1.519	± 0.468	1.288	± 0.503	**0.008**		
Evenness	0.539	± 0.148	0.508	± 0.139	0.491	± 0.169	0.501		
Simpson index	0.686	± 0.191	0.646	± 0.167	0.581	± 0.198	0.093		
Average palatability	27	± 12	25	± 20	23	± 14	0.724		
Cover annuals [%]	28.7[a]	± 11.89	26.6[a]	± 11.88	20.2[b]	± 9.32	**0.013**	Log	**0.013**
Vegetation cover [%]	23.7[a]	± 5.97	20.3[b]	± 5.70	15.1[c]	± 6.37	**< 0.001***		
Cover life form [%]									
Chamaephytes	0.9[a]	± 2.02	0.68	± 1.33	4.86	± 6.47	**< 0.001***	Log	**< 0.001**
Geophytes	25.2[a]	± 12.54	24.2[a]	± 12.32	14.7[b]	± 10.79	**< 0.001**		
Hemicryptophytes	0.1	± 0.10	0.11	± 0.26	0.17	± 0.59	0.75		
Phanerophytes	0.7[a]	± 1.76	0.2[b]	± 0.44	0.0[b]	± 0.06	**0.009**	Log	**0.007**
Structural parameters									
Cover fine material [%]	95.7	± 5.84	97.6	± 3.81	99.1	± 2.38	0.011*		
Cover biotic crust [%]	58.9	± 30.98	60.8	± 32.22	56.2	± 32.68	0.811		
Cover dead wood [%]	2.2	± 2.00	2.1	± 2.06	3.7	± 3.45	0.009	Rank	0.073
Cover soft litter [%]	2.3	± 3.14	2.6	± 3.23	1.3	± 1.74	0.15		
Cover dung [%]	0.06	± 0.11	0.04	± 0.09	0.04	± 0.05	0.562		
Cover bioturbation [%]	0.5[a]	± 1.12	1.1[a]	± 2.86	14.8[b]	± 26.38	**< 0.001**	Rank	**< 0.001**
Cover sheet erosion [%]	0.8	± 0.83	1	± 0.74	0.5	± 0.68	0.018*		
Cover rill erosion [%]	0.7[a,b]	± 0.91	0.8[a]	± 0.85	0.3[b]	± 0.55	0.023		

Df residual = 118, $N = 121$ ($N_{Matrix} = 23$, $N_{Fringe} = 68$, $N_{Centre} = 30$)

Asterisks (*) indicate application of significance level $p = 0.01$ due to heterogeneity of variances and skewed or non-existent normal distribution. Otherwise significance level was $p = 0.05$. Significant *p*-values are bold. Superscript letters (a) and (b) indicate homogenous groups according to Tukey's HSD at $p = 0.05$ or $p = 0.01$ respectively.

heuweltjies is presumed to be of zoogenic origin (i.e. accumulation of nutrients by termites; Midgley & Musil 1990, Petersen 2008) and the continued habitation of the heuweltjies by burrowing animals.

Heuweltjies are dominated by opportunistic plant species, which can cope with bioturbation (Esler & Cowling 1995, Röwer 2009, compare also Table 2). These species are able to complete their life cycles within a short time period (Anderson & Hoffman 2007) and the heuweltjie soils are able to satisfy their relatively high nutrient requirements (Knight et al. 1989). In the Lowland Succulent Karoo, for instance, they are often covered by the *Foveolina dichotomoa-Eberlanzia cyathiformis* unit, which is dominated by the mat-forming leaf-succulent shrub *Eberlanzia cyathiformis* (Vygie) and the annual Asteraceae *Foveolina dichotoma* (Stinkkruid) (Röwer 2009). These vegetation patches on heuweltjies are embedded in a matrix of low vegetation, which is often dominated by the dwarf shrub *Galenia fruticosa* (Porselein) and the creeping *Cephalophyllum inaequale* (Rankvye). The combination of the patches and matrix belongs to the *Zygophyllum cordifolium-Cephalophyllum inaequale* unit.

Similarly strong gradients in soil salinity and soil pH that occur at different spatial scales have also been described for the quartz fields, which are another azonal and unique habitat type typical of the Succulent Karoo. The soil conditions and vegetation differ significantly from surrounding zonal habitats (Schmiedel & Jürgens 1999, Schmiedel 2002, Haarmeyer et al. 2010). The plots on quartz fields in the Knersvlakte have lower and more variable soil pH values as well as higher conductivity than the zonal soils, whereas the latter typically possess a higher carbon content (Schmiedel 2002, Haarmeyer et al. 2010). These differences in soil features between azonal quartz fields and zonal soils drive species turnover in the landscape and contribute significantly to the local endemism, which is characteristic of the Succulent Karoo. In 2007, we compared species numbers and the abundance of individual plants for plots (100 subplots of 400 cm^2 nested within a 20 m x 50 m plot) inside (N = 27) and outside (N = 24) of quartz fields in the Knersvlakte (around Observatories S26–S28). Although less individuals and species were recorded for the quartz field plots (quartz: 186 ± 116; zonal soil: 330 ± 197), they possessed higher numbers of endemic individuals (quartz: 75 ± 42, zonal soil: 34 ± 12) and species (quartz 8 ± 3; zonal 6 ± 2) (Haarmeyer et al. 2010). This supports the account of the southern African quartz field flora by Schmiedel (2004), which recorded an extraordinarily high number of local endemics. Out of the 67 obligate quartz field taxa, 63 taxa are endemic to the Knersvlakte (Schmiedel 2004). The obligate quartz field flora thus contributes 40% of the approximately 150 endemic Knersvlakte taxa recorded by Hilton-Taylor (1994).

The described diversity at the landscape scale can be explained by interactions between soil features at different spatial scales ranging from the medium- (app. 100 m^2) to micro-scale (< 1 m^2). In the following we focus on typical patterns of such soil features that drive plant species composition at different spatial scales, but that may also be influenced by plants at the same time, within the Succulent Karoo landscape.

Medium-scale drivers of vegetation patterns

Medium-scale soil patterns (ca. 100 m^2) are driven by abiotic and biotic factors. The abiotic factors are topography, local variations in parent rock material that influences the content of coarse fragments, soil depth, soil salinity, acidity and the nutrient content at a given site. Small variations in topography result in run-off (leaching) or run-on (accumulation of water-dissolved ions) of surface water and result in remarkable patchiness of soil types which again drives species turnover within a short distance. Typical phenomena of medium scale abiotic patterns will be described using the quartz field habitats as an example. The biotic factors that drive medium scale soil heterogeneity are the above-mentioned heuweltjies.

Soils of quartz fields do not only differ from surrounding zonal soils as described above, and abrupt changes in chemical and physical soil features are also found between different types of quartz fields, resulting in a high turnover of quartz-field plant communities (Schmiedel & Jürgens 1999, Schmiedel & Mucina 2006). Gradients of soil salinity within quartz fields in the Knersvlakte were negatively related to mean species richness per subplot (400 cm^2) and plot (1000 m^2) as well as to the abundance of endemic species. As salinity intensifies the effects of drought by increasing the osmotic pressure in the soil (Campbell & Reece 2005), it can be assumed that soil water availability in combination with salinity are the main drivers of the abundance and diversity of plant species on quartz (Schmiedel 2002, Haarmeyer 2009). This medium-scale soil pattern can easily be destroyed by mechanical disturbance through trampling, ripping, or ploughing of the soil. Plots on disturbed quartz fields in the Knersvlakte showed significantly lower numbers of local endemics compared to undisturbed plots (Etzold 2006).

The soil transect across a heuweltjie on a slope in Soebatsfontein (Fig. 1) showed strong changes of soil features from the matrix soil to the soil at the centre of a heuweltjie (Petersen 2008). Fig. 1 reveals the high occurrence of durinodes (soil fragments cemented by silica) at the centre of the heuweltjie and towards the matrix as well as massive duripans (soil horizons cemented by silica) outside the heuweltjie. A general trend of higher values of silt, soil pH, calcium carbonate, electrical conductivity, and total nutrient content is evident at the centre of heuweltjies compared to surrounding soils (Table 1). Additionally, soluble salts such as sodium chloride (NaCl) accumulate in the mounds, causing increased electrical conductivity (up to 40 mS/cm) and high osmotic pressure, which result in water stress for plants. These soil conditions on heuweltjies influence the total vegetation cover as well as species richness and Shannon diversity indices, which decrease towards the centre of heuweltjies (Table 2). This can be explained by continuous disturbance caused by the burrowing activities of small mammals (bioturbation) and—depending on topography and osmotic potential—also poor water availability on heuweltjies (Francis et al. 2007, Petersen 2008). However, although the alpha diversity (i.e. diversity within a plant community) is low, heuweltjies contribute strongly to the habitat diversity and thus to beta diversity (species turnover between plant communities) in the landscape. Although heuweltjies cover only about 12% of the land surface in the study area, the variation of soil and structural parameters, diversity, and vegetation was about the same magnitude as found for the entire communal land area (Röwer 2009).

Plant-soil-interaction at the micro-scale

Soil patterns at the micro-scale scale (< 1 m^2) are typically caused by local interactions between plants or animals and the soils. In this context, we describe the effects of abiotic soil surface features, the role of biological soil crusts, as well as the fertile island effects of vascular plants.

a) Influence of soil surface features on plant species composition: Soil surface characteristics on quartz fields may also influence species composition at the micro-scale. The density of quartz gravel cover on the soil surface (i.e. sparse to complete cover) in the Knersvlakte, for instance, influenced species composition of seedlings (Haarmeyer et al. 2010). We found significantly more seedlings on sub-plots (400 m^2) that were covered with more than 66% quartz gravel than on those with sparser quartz cover. This effect was even more pronounced when considering only Aizoaceae seedlings, whereas no differences in the numbers of non-Aizoaceae seedlings could be detected (Table 3).

This finding corresponded with the generally higher abundance of Aizoaceae seedlings recorded in quartz field plots than in the zonal habitat plots (Haarmeyer et al. 2010) and suggests a strong influence of quartz cover on recruitment of Aizoaceae seedlings. A reason for this could be that the soil between the quartz stones is less exposed to solar radiation and is therefore generally cooler

Table 3: Numbers of seedlings per 400 cm² sub-plots at low, medium and high quartz cover densities in the Knersvlakte

Microhabitat (quartz cover)	Low mean ± SD) *N = 46*	Medium (mean ± SD) *N = 39*	High (mean ± SD) *N = 30*	*p*-value
Number of seedlings	0.46 ± 0.57[ab]	0.34 ± 0.58[a]	0.87 ± 0.98[b]	**0.013**
Number of Aizoaceae seedlings	0.26 ± 0.32[a]	0.21± 0.39[a]	0.74 ± 0.85[b]	**< 0.001**
Number of non-Aizoaceae seedlings	0.18 ± 0.40	0.13 ± 0.32	0.13 ± 0.31	0.642

Different superscript letters indicate significant differences among levels.

Table 4: Differences in soil properties between "open soil" and the soil under plant canopies ("plant canopy soil") for three topsoil layers

Parameter	0–1 cm *N*	mean ± SD	1–5 cm *N*	mean ± SD	5–10 cm *N*	mean ± SD
pH_{H2O}	50	0.37 * ± 0.54	50	0.40 * ± 0.48	49	0.70 * ± 0.57
pH_{CaCl}	50	0.51 * ± 0.51	50	0.56 * ± 0.72	49	0.65 * ± 0.82
C_{inorg} [%]	20	–0.18 * ± 0.12	20	–0.16 * ± 0.13	20	–0.14 * ± 0.16
C_{org} [%]	50	1.00 * ± 2.06	50	0.02 ± 0.58	49	–0.12 ± 0.64
N_t [%]	50	0.047 * ± 0.070	50	0.005 ± 0.029	49	–0.008 ± 0.030
C/N-ratio	50	0.96 ± 3.8	50	–0.7 ± 1.7	49	–0.84 ± 2.5
P_{dl} [g/kg]	19	–0.07 ± 0.09		–		–
K_{dl} [g/kg]	19	0.22 * ± 0.31		–		–

The difference between means after the dataset was standardised are presented. Negative values indicate lower contents for "plant canopy soil" sites compared to "open soil" sites. * = significant differences between means; pH_{H2O} = pH measured in water; pH_{CaCl} = pH measured in 0.01 M $CaCl_2$-solution; C_{inorg} = inorganic carbon; C_{org} = organic carbon; N_t = total nitrogen; P_{dl} = double lactate extractable (plant available) phosphorus; K_{dl} = double lactate extractable (plant available) potassium (Herpel 2008)

(Schmiedel & Jürgens 2004) and moister (C. Musil, pers. comm.) than soils without quartz cover. As water uptake and moderate daily maximum temperatures are essential for seedling survival of succulents that grow close to the soil surface (Nobel 1984), the quartz habitat seems to better fulfil germination requirements for Aizoaceae seedlings than the zonal soils without quartz cover. The importance of quartz cover for Aizoaceae species found by Haarmeyer et al. (2010) is in line with a study on disturbed quartz fields (due to installation of water pipelines) in the Knersvlakte. Etzold (2006) compared species richness per plant family inside and outside the disturbed quartz fields and found approximately 20% less Aizoaceae species on the disturbed quartz fields, while the number of (mainly non-succulent) Asteraceae species increased by approximately 100%.

b) Influence of biological soil crusts on soil features: Biological soil crusts (i.e. cyanobacteria, algae, lichens, bryophytes, see Büdel et al. 2009, Article III.3.4, Subchapter IV.4.5) can also influence their environment in various ways. For example, they promote the accumulation of organic carbon (Evans & Lange 2001) and nitrogen (Belnap 2002b), stabilise the soil surface, and reduce water infiltration into the soil (Belnap 2006, Warren 2001). We studied soil patterns with regard to these micro-scale features (Herpel 2008).

Biological soil crusts only occur on the upper few millimetres of soils. Nonetheless, our scientific soil study in the Lowland Succulent Karoo (Observatory S22) revealed significant increases in soil pH values by up to 0.5 pH-units in three different soil depth layers (0–1 cm, 1–5 cm, and 5–10 cm) (Herpel 2008). This was valid for all sites sampled at the micro-scale within the Soebatsfontein Observatory although the sample sites were located on strongly differing parent materials, ranging from calcareous heuweltjie substrates to acidic matrix soils on the slopes. The underlying process of this phenomenon is assumed to be bio-alkalisation triggered by photosynthetic activity of the organisms within the crusts (Büdel et al. 2004).

The comparison of biological soil crusts and non-crusted open soils also showed higher silt content within the first few centimetres of soils with crusts and a corresponding increase in the content of particular elements in the soils (e.g. Aluminium, Zinc, and Manganese). Zhang et al. (2006) ascribed this to the sticky surfaces of the biological soil crusts that capture silty dusts, which leads to the enrichment and patchy distribution of correlated total elements. Biological soil crusts also reduced water infiltration rates into the soils at Soebatsfontein. Soils covered by biological soil crusts were always among those that had the lowest infiltration rates and, in most cases, exhibited lower infiltration rates than adjacent open soil sites (Herpel 2008).

c) Effects of vascular plants on soil features: Our study at Soebatsfontein also showed that leaf-succulent dwarf shrubs have small-scale effects on their abiotic environment by creating fertility islands underneath their canopies. We found that the topsoil below plant crowns relative to adjacent open soil was enriched by organic matter, had increased pH-values and higher coarse soil fraction contents, and was also partly enriched by nutrients (Table 4). The underlying processes of the fertility islands, where litter fall leads to the accumulation of organic matter below the crowns of shrubs, is well described by Hook et al. (1991). The redistribution of topsoil material by wind and water as well as the trapping of fine material below canopies increase this effect. In addition, nutrients taken up by roots from inter-canopy areas are accumulated in plant tissues (e.g. leaves) and deposited again as litter beneath the plants. Animals seeking shelter under plants contribute to the formation of fertility islands by leaving behind excrement and unconsumed food components. This fertile island effect, which also seems to depend on the growth-form and average lifespan of the plant species (Stock et al. 1999), results in horizontal patchiness of soil fertility and structure at the micro-scale.

Conclusions

Soil patterns in the Succulent Karoo occur at various spatial scales and are caused by different processes. Patterns already occur at the micro-scale where they arise from mutual interactions between abiotic soil surface features, biological soil crusts, and vascular plants. The occurrence of biological soil crusts, vascular plants, and animal activity depends on the soil type but these factors, in turn, also change the soils conditions by accumulating organic material and nutrients, creating micro-disturbances by digging, and altering soil surface structure (Fig. 2). These micro-scale patterns of soil heterogeneity again are nested within the medium-scale pattern of soil types that is mainly driven by topography (e.g. run-on, run-off of surface water), geology, and the heuweltjies of zoogenic origin. The resulting steep gradients in the chemical and physical features of the soils are characteristic of the Succulent Karoo. The mosaic of medium-scale patterns accumulate at the macro-scale, contributing to the landscape diversity of the area, which has a strong influence on the biodiversity of the Succulent Karoo. The predominance of gentle rain showers in the Succulent Karoo (Desmet 2007), which are typical of the winter rainfall regime, have less of a leaching or erosive effect on the soils than summer rainfall events and certainly also contribute to the maintenance of these small-scale patterns.

In summary, micro- and medium-scale features in the Succulent Karoo play a crucial role in the maintenance of biodiversity at the landscape scale. Unsustainable land management may have a negative effect on these patterns: Severe trampling, ploughing, or mechanical destruction due to infrastructure development destroys the small-scale heterogeneity in soils, impacts biological soil crusts (Subchapter IV.4.5) and thus homogenises the plant species composition. In particular, our studies on quartz fields in the Knersvlakte showed that local and habitat endemics seem to be most strongly affected by such homogenising impacts of trampling and ripping of soil surface (Etzold 2006, Haarmeyer et al. 2010). Protection of small- and medium-scale heterogeneity of soil patterns should be the highest priority of management measures in order to maintain the extraordinarily high soil and plant diversity of the Succulent Karoo landscape. Once destroyed, the ecosystem may take decades to recover (Subchapters IV.4.3, IV.4.4).

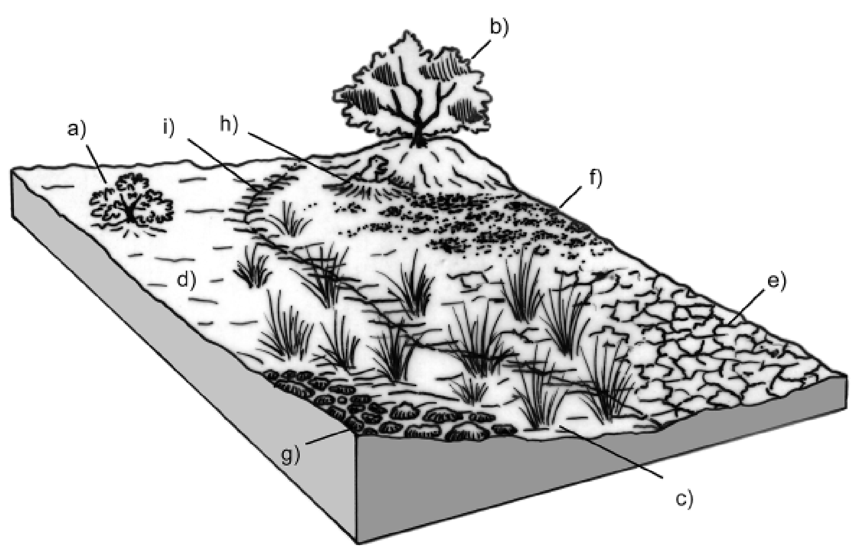


Fig. 2: Diagrammatic representation of micro-features in an idealised dryland landscape. a) dwarf-shrub, b) larger shrubs, c) tussock grasses, d) open soil patch, e) mineral soil crust, f) biological soil crust, g) pebble covered areas, h) disturbance spot caused by digging animals, and i) small depressions or channels. Source: Herpel 2008.

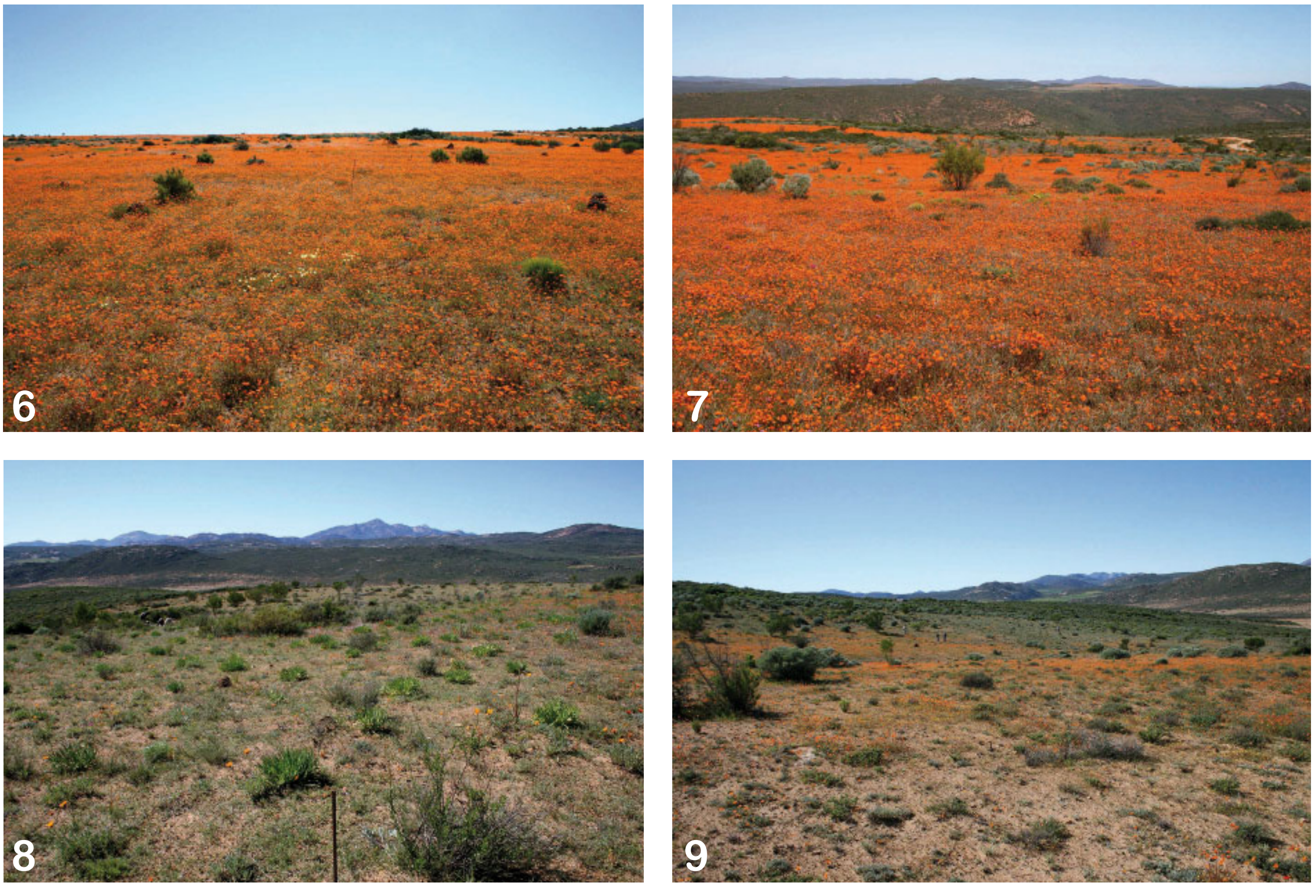
4.3 Old field succession in the Namaqua National Park, Succulent Karoo, South Africa

[M.W. van Rooyen, R. Henstock & H. van der Merwe]

Introduction

Private land ownership in Namaqualand began during the late 19th century and brought an end to the nomadic lifestyle of both the KhoiKhoi and European 'Trekboere'. Permanent human settlement at the same time necessitated the cultivation of crops. Crop cultivation was initially primarily to provide food for daily living, although it was also used to provide fodder for livestock during dry periods. Some farmers, especially in the higher rainfall parts of Namaqualand, later started clearing large tracts of land for commercial crop production.

The normal farming practice in the region is to cultivate a field for one year and then to let it lie fallow for a year or two before cultivating it again. These fields lying fallow between cultivation often produce the breathtaking mass displays of spring flowers for which Namaqualand has become world renowned (van Rooyen 1999). The springtime floral spectacle draws thousands of tourists annually and is a valuable source of income to the region (James et al. 2007). In 1988, the South African Nature Foundation (later incorporated into WWF-South Africa) bought the 930 ha farm Skilpad as a wildflower reserve as the farm was well-known for its springtime flower displays on the old fields. When the reserve was later donated to SANParks to become part of the Namaqua National Park, it was on condition that the old field vegetation would still be managed to provide annual shows of wild flowers. Although the mass effect on the abandoned croplands is created by the dominance of a few pioneer species and is associated with a low diversity, SANParks are honouring



Photos 6–9: The four monitoring sites in 2009, 6) abandoned 18 years previously; 7) abandoned 19 years previously; 8) abandoned approximately 25 years previously; and 9) abandoned approximately 55 years previously. Photo: Noel van Rooyen.

this agreement and a small number of the abandoned fields on the Skilpad section of the park are still ploughed from time to time to produce mass flower displays. These disturbed fields cover a minute portion of the park and the bulk of the abandoned fields are left to recover naturally.

Despite Namaqualand being a marginal environment for crop production, it is estimated that croplands covered nearly 30,000 ha in the early 1970s (Hoffman & Rohde 2007). As a result of increased production costs since then, farmers have been forced to cultivate fewer fields (van der Merwe 2009), and the area under cultivation has declined by approximately two-thirds. Many abandoned croplands lie scattered throughout the Namaqualand landscape as a consequence. A similar trend of increasing land abandonment has been reported worldwide as a result of environmental and socio-economic changes (Cramer & Hobbs 2007, Cramer et al. 2007).

In general, studies on secondary succession on old fields in arid regions are scarce (Otto et al. 2006), and little has been reported for the Succulent Karoo or Namaqualand (van Rooyen 2002, Witbooi & Esler 2003, Simons & Allsopp 2007). The objectives of this study were to investigate natural vegetation changes on abandoned fields in the Namaqua National Park over time in order to aid future planning and effective management of the many old fields scattered throughout this extensive conservation area. Understanding the process of natural vegetation change, and the rate at which it occurs could also assist in developing techniques that could enhance restoration possibilities of old fields.

Methods

Chronosequence

Vegetation recovery on four abandoned fields, differing in time since last cultivation was examined from 1994 to 2009 to detect changes in species composition and diversity. When the first surveys were conducted in 1994, the times since last cultivation for these fields were 3, 4, ~10, and ~40 years respectively (Photos 6–9). A step-point survey of 1,000 points was conducted annually in springtime at each monitoring site to determine the frequency of species. At each point, the nearest annual as well as the nearest perennial species were recorded, noting which of the two had in fact been the closest. In this way the annual species could be analysed separately from the perennial species, but a combined analysis, ignoring life duration, could also be undertaken. The significance of a linear regression of species richness against time was analysed in Graphpad Prism 4.03 for Windows (GraphPad software, San Diego, California, USA, www.graphpad.com).

Floristic analysis

The Braun-Blanquet method of vegetation sampling was used to conduct a floristic analysis at 62 sites on the abandoned fields in and around the Namaqua National Park during 2006 and 2007. This paper will only report on the results of 31 sampling sites on the Skilpad section of the park as well as on the adjacent farmland. An analysis of the floristic data was conducted using the TURBOVEG and MEGATAB computer packages (Hennekens & Schamineé 2001) and refined using Braun-Blanquet procedures (Werger 1974).

The SYN-TAX computer program (Podani 2001) was used to ordinate the standardised (natural logarithm standardisation) floristic data of the relevés and monitoring sites using Principal Co-ordinate Analysis (PCoA) and the Bray Curtis distance measure.

Results and discussion

Chronosequence

Over the past 15 years, total species richness increased with time since abandonment at all four monitoring sites (Fig. 3a). This increase was mainly due to the significant increase in perennial species (Fig. 3b). Only at monitoring sites 1 and 2, where monitoring was commenced soon after abandonment, was there a significant increase in annual species richness with time. After 16 years of monitoring, the annual species richness at all four sites were quite similar, but did not show any signs of decreasing even after > 50 years of abandonment (Fig. 3c). Species composition of the perennial species showed a clear directional trend over the monitored years (Fig. 4), whereas annual species composition did not show a similar directional trend. The annual species composition as well as richness was dictated by the timing and amount of rainfall in a growing season.

Floristic analysis

The natural vegetation in the Skilpad section of the Namaqua National Park falls within the Namaqualand Klipkoppe (SKn1) of Mucina et al. (2006). The area lies on the escarpment with the altitude ranging from 620 to 750 m above sea level and the predominant land type in which the croplands were established is Ag94 (Agricultural Research Council, undated) with red-yellow apedal, freely

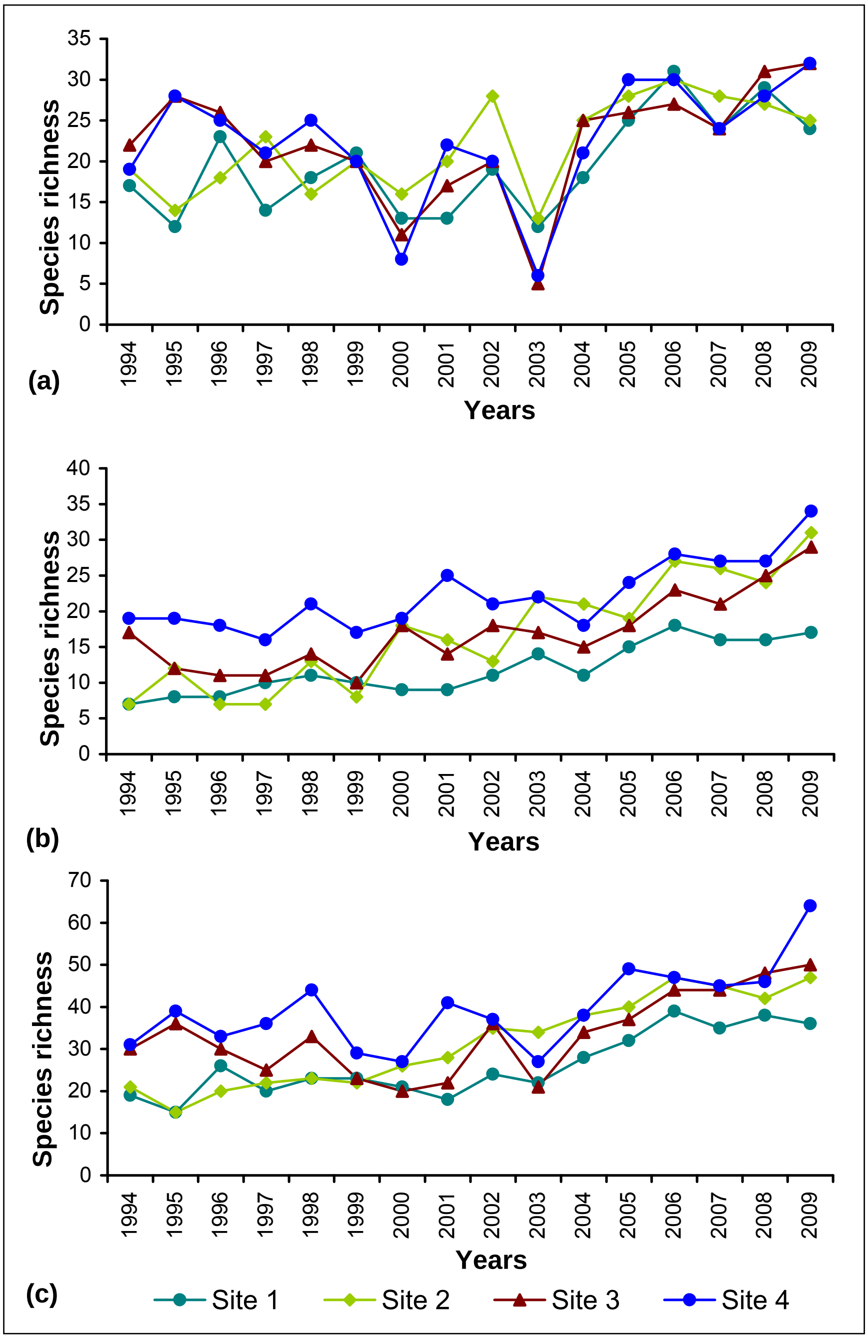


Fig. 3: Changes in species richness of (a) annual species (b) perennial species and (c) total species at the four monitoring sites from 1994 to 2009.

drained soils that are less than 300 mm deep. The vegetation of the old fields around the farm Skilpad belonged to a single vegetation community, the *Ursinia cakilefolia* old field vegetation, and could be subdivided into four sub-communities. In general, the vegetation was characterised by the presence and high cover of *Ursinia cakilefolia*, *Gazania leiopoda*, *Felicia dubia*, *Heliophila variabilis*, *Leysera gnaphalodes*, *Pentaschistis tomentella*, *Conicosia elongata*, and *Dimorphotheca sinuata*.

The four sub-communities represented a gradient in time since abandonment, with sub-community 1.1 being in an early successional stage and sub-community 1.4 in a late successional stage. The first sub-community (*Leysera gnaphalodes-Ursinia cakilefolia* old field vegetation) represented those fields in the Namaqua National Park that were still regularly disturbed to maintain a flowering display for tourists. The second sub-community (*Heliophila variabilis-Ursinia cakilefolia* old field vegetation) was found

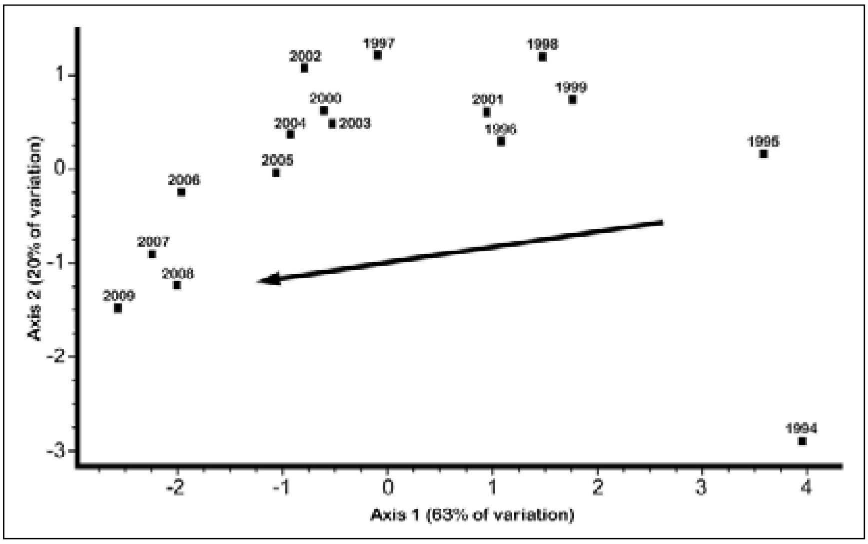


Fig. 4: Directional changes in species composition at monitoring site 1 from 1994 to 2009.

towards the eastern part of the Skilpad section. Many of these old fields were actively cultivated before the Skilpad Wildflower Reserve was established, but have not been disturbed since then. In general, the old fields in this sub-community were from 12 to 15 years old. Sub-community 1.3 (*Felicia bergeriana-Ursinia cakilefolia* old field vegetation) was transitional between sub-communities 2 and 4, and included sites in the park as well as in the adjacent farmland. Some of the fields in the park were abandoned only ~20 years ago, whereas others had already been abandoned for more than 40 years before the park was proclaimed and were therefore at least 55 years old at the time of the study. In contrast, the fields on the adjacent farmland were estimated to be only ~15–20 years old at the time of the study. Sub-community 1.4 (*Stipagrostis zeyheri-Ursinia cakilefolia* old field vegetation) represents those fields that had been cultivated more than 50 to 80 years ago. Large perennial shrub species such as *Searsia horrida*, *Wiborgia mucronata*, *Nylandtia spinosa*, and *Dodonaea viscosa* were prominent in this sub-community.

The results of the floristic analysis were used to analyse the contributions of the different life forms towards the vegetation cover. The relative contribution of the perennial species increased from 40 ± 3% (mean ± standard error) in sub-community 1.1 to 47 ± 10%, 48 ± 6% and 73 ± 8% in sub-communities 1.2, 1.3, and 1.4 respectively. Conversely, the relative contribution of the annual species to the vegetation cover showed a decrease from 57 ± 3% to 46 ± 8% to 46 ± 5% and finally to 23 ± 7% from sub-community 1.1 to 1.4. Furthermore, within the annual species it was noted that the contribution of the species producing mass displays decreased, whereas the contribution made by non-showy annual species increased. The relative contribution made by the geophytes remained fairly constant and ranged from 3% to 7%.

Conclusions

Overall, results show that secondary succession on the old fields in Namaqualand proceeds very slowly. The vegetation on many old fields abandoned more than 50 years ago was still clearly distinguishable from the surrounding vegetation, although the vegetation on the field that had not been cultivated for more than 80 years could hardly be distinguished from the natural vegetation. In spite of all sites having a ploughing history in common, recovery of the vegetation depends upon other farming practices on the old fields such as grazing regime (Bonet 2004, Cadenasso et al. 2002), number of times ploughed, crops planted (Myster & Pickett 1990, Bonet 2004), and the rainfall amount and temporal distribution in the year of abandonment (Myster & Pickett 1990, Pickett et al. 2008).

Most studies on vegetation succession on abandoned croplands show a sequence in dominance of life forms from annuals, through herbaceous perennials to woody perennials (Debussche et al. 1996, Bazzaz 2000). An investigation of the contribution of the different life forms to the vegetation cover in this study revealed the same pattern. However, an analysis of species richness did not show the anticipated decrease in species richness of the annual species.

As time progressed after abandonment of a field, dominance changes occurred in the species composition, with the annual species assemblages changing to include fewer species producing showy flowers. Furthermore, the visual mass display effect also depended on the cover of the perennial species present.

The spectacular displays of flowering annuals in spring each year is the foundation of the tourism industry in Namaqualand (James et al. 2007). Historically, the croplands on Skilpad were intentionally disturbed to promote good flower displays to attract visitors. Although deliberate disturbance is not desirable in a national park, the results of the current study confirm that some disturbance does seem essential to maintain a spectacular flowering display. The practice of tilling a few selected fields along the circular tourist route in the Namaqua National Park approximately every four years will therefore have to be continued. Although vegetation change is slow on the abandoned croplands, natural recovery does occur and it is recommended that all other abandoned croplands in the park are allowed to recover naturally.

4.4 Restoring degraded rangelands in the Succulent Karoo: lessons learnt from four trials

[W. Hanke & U. Schmiedel]

Introduction

Aim of the study

In this Subchapter we collate the findings of four restoration experiments, which were conducted within the context of the BIOTA project on degraded rangelands

Photos 10 and 11: Comparison of rangelands the Richtersveld, Succulent Karoo. 10) *Brownanthus pseudoschlichtianus*-dominated rangeland in good condition and 11) degraded rangeland with sparse vegetation consisting of annual and pioneer species. Photos: Wiebke Hanke.

in the Succulent Karoo. The aim of the experiments was to identify resource manipulations that are able to restore functionality of the ecosystem and the vegetation cover. The experiments were located at different regions and monitored over several years, which allows an assessment of their general applicability for the Succulent Karoo. In this compilation we attempt to answer the following questions:

1. What were the effects of different treatments on soil and vegetation parameters?
2. Which processes determined the success or failure of the treatments?
3. What are the practical implications for rangeland restoration in the Succulent Karoo?

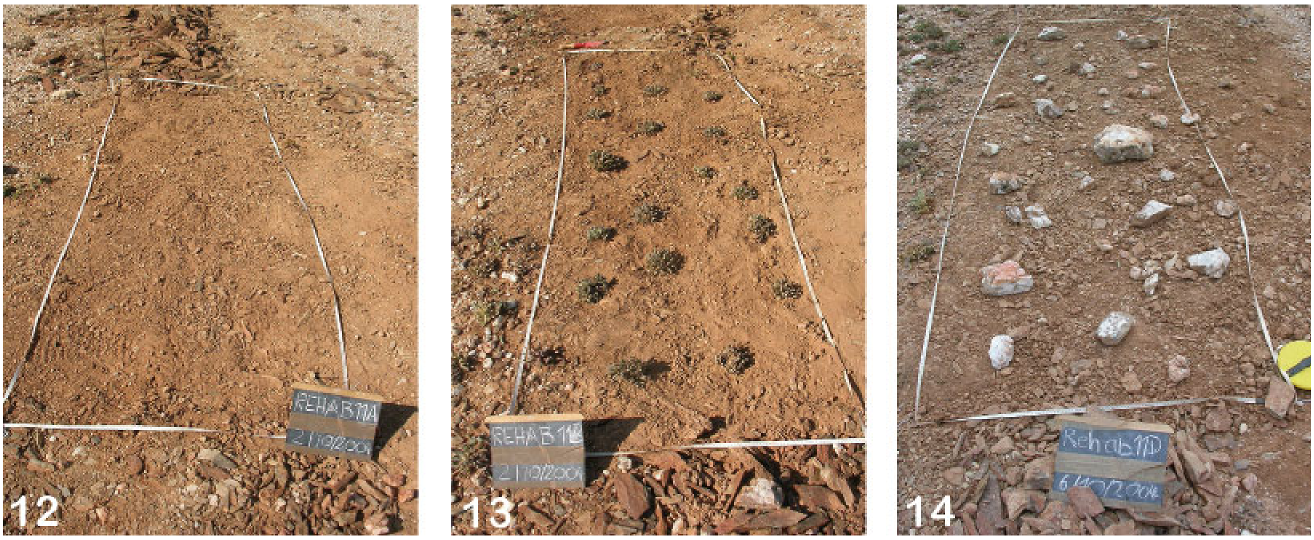
Rangeland degradation in the Succulent Karoo

The Succulent Karoo Biome is a winter rainfall semi-desert, favouring a succulent dwarf shrub vegetation of exceptionally high diversity (Cowling et al. 1999, Subchapters IV.4.1, IV.4.2). The majority of the area is used for livestock farming with sheep and goats and, to a lesser extent, also cattle and donkeys (Anonymous 1986). With the arrival of European settlers the transhumant strategies of the indigenous pastoralists who moved their sheep and goats between summer and winter rainfall areas came to an end. Instead, the pastoralists were constrained within relatively over-crowded, communally-managed areas where their livestock movements were restricted to smaller areas than had historically been the case (Hoffman et al. 2007). Inappropriate management strategies and overstocking have led to a significant transformation of these communally-managed areas and a decline in rangeland quality (Todd & Hoffman 2009). Under heavy grazing, the diverse dwarf shrub communities tend to be replaced by few, often unpalatable species. Heavy grazing also results in the replacement of perennial shrubs by ephemeral species (Todd & Hoffman 1999). Since the abundance of the ephemerals is highly dependent on rainfall, farmers have to deal with large fluctuations in forage resources (Vetter 2005). Where perennial vegetation has been reduced, bare patches predominate during the dry period (Photos 10 & 11). This affects the soil quality negatively, which is further compounded by livestock trampling. The rich biological soil crusts (see also Article III.3.4) are disturbed (Rutherford & Powrie 2010, Subchapter IV.4.5) and soil stability decreases (Petersen et al. 2004). Further, Beukes & Ellis (2003) found that degraded soils are shallower due to erosion and therefore have a poorer water holding capacity.

Rangeland transformation in the Succulent Karoo may disrupt crucial ecological processes and landscape functions. It takes decades for the transformed rangelands to recover (Hoffman & Rohde 2007, Richardson et al. 2007), because poor water supply (Beukes & Cowling 2003, Botha et al. 2008) and poor representation of perennial species in the seed bank (de Villiers et al. 2003) restrict autogenic vegetation recovery. Active restoration measures in combination with improved management strategies may induce rehabilitation within shorter and practically relevant time-scales.

Environmental context for restoration in the Succulent Karoo

The characteristic features of the Succulent Karoo climate result in specific environmental and ecological processes, which should be taken into consideration during the development of restoration strategies (Carrick & Krüger 2007). Most of the area receives winter rainfall of less than 150 mm per annum (Cowling et al. 1999), but compared to other desert regions rainfall is reliable and prolonged droughts rarely occur (Desmet & Cowling 1999). Precipitation during the growing season usually occurs as a ‘drizzle’ of low to moderate intensity or in the form of fog or dew (Desmet & Cowling 1999) which wets the soil only to a shallow depth. The Succulent Karoo differs from most other (semi-) arid environments also in terms of the mild temperatures experienced in the growing season during winter and early spring (Cowling et al. 1999).



Photos 12–14: Restoration plots shortly after treatment application in Knersvlakte quartz fields disturbed by the pipeline construction. 12) Levelling (control), 13) levelling and planting of C. spissum individuals, and 14) levelling and scattering of quartz stones. Photos: Sophia Etzold.

Both water and wind erosion and consequently deposition also play an important role in habitat degradation and recovery processes. Water erosion is often associated with the heavy thunderstorms and subsequent surface run-off which can occur in the region during the summer months while the strong winds, which prevail throughout the year in most areas can result in significant levels of wind erosion (Desmet & Cowling 1999).

Research on rangeland restoration has only just begun

Degradation of (semi-) arid rangelands poses a serious problem worldwide and their restoration has become an important field of research, which is gaining in prominence. Various efficient methods have been described for practice (e.g. Dregne 1992, Coetzee 2005, Bainbridge 2007), but up to now, only a few of them have been tested under the unique environmental conditions of the Succulent Karoo. Apart from the studies in the BIOTA context, to our knowledge only three types of active rangeland restoration treatments have been scientifically evaluated and published for this biome, namely: functional plants (i.e. plants with a functional role such as facilitation of other plants or reduction of soil erosion) (Anderson et al. 2004, see also Gabriels et al. 2003), application of organic mulch (Beukes & Cowling 2003), and gypsum treatment (Beukes & Cowling 2003). They all improved soil properties and offered considerable potential to enhance the re-establishment of vegetation. The studies showed that functional transplants and organic mulch should be further investigated, whereas gypsum did not prove to be cost-effective due to high transport costs. The findings from an experiment by Simons & Allsopp (2007) will be reported in the present compilation together with the BIOTA experiments, as it is situated in the direct vicinity of a BIOTA observatory and its monitoring was partly conducted within the BIOTA project.

Further restoration treatments have been tested in informal trials by local farmers. These experiences should be captured and incorporated into the restoration research (Botha et al. 2008, see Article III.8.2). Also, the experiences from mine spoil restoration projects (Blignaut & Milton 2005, Carrick & Krüger 2007) can be included in the development of restoration methods for rangelands. These studies have shown that floristic features like the occurrence of succulence and the high drought tolerance of many seedlings present good opportunities for the success of species re-introductions.

Description of the BIOTA restoration experiments

The restoration experiments were conducted in degraded rangelands in the vicinity of four BIOTA Observatories (see Table 5) in the major ecological regions of the Succulent Karoo: at two farms on the Soebatsfontein commonage (Coastal plain) (Meyer 2009), at sites on the Paulshoek commonage (Namakwaland Klipkoppe) (Simons & Allsopp 2007), at sites on the Eksteenfontein commonage (Richtersveld) (Hanke et al. 2010, submitted), and on the farm Ratelgat (Knersvlakte) (Etzold 2006, Meyer 2009).

In this article we integrate the findings of all treatments applied at more than one of these sites: i.e. livestock exclusion, introduction of brushpack, dung or stones, soil surface structuring by microcatchments, and the use of plants with a special functional role. The treatments aimed to reverse degradation caused by overstocking, except for the site in the Knersvlakte (Photos 12–14) where disturbance was caused by the construction of a subterranean water pipeline.

The key data and references to the experiments are listed in Table 5. The evaluation at all four sites included the response of natural plant recruitment with respect to growth form. Furthermore, the evaluation of each experiment is characterised by a special focus. The most important site specific installation and evaluation characteristics for the experiments are noted below.

Soebatsfontein: The evaluation focussed on soil chemical parameters. Effects on the total amount of nitrogen and carbon, C/N ratio, pH, and electrical conductivity were assessed in mixed soil samples from

Table 5: Key data of the rangeland restoration experiments conducted in the framework of BIOTA in the Succulent Karoo, South Africa, during 1999–2009

	Eksteenfontein (Richtersveld)	Soebatsfontein (Coastal plain)	Farm Ratelgat (Knersvlakte)		Paulshoek (Namakwaland Klipkoppe)
			Quartz	Zonal	
Related Observatory	Koeroegap Vlakte (S18)	Soebatsfontein (S22)	Ratelgat (S27)	Ratelgat (S27)	Paulshoek (S24), Reemhoogte (S25)
Time frame	Start 2007, revisit 2008	Start 2004, revisits annually 2005–2008	Start 2004, revisits 2005, 2008	Start 2004, revisits 2005, 2008	Start 1999, revisits monthly 1999–2001
Degradation cause	Overgrazing	Overgrazing	Pipeline installation	Pipeline installation	Overgrazing
Experimental design	Split-plot (fenced/unfenced): 5 whole plots, each with 10 subplots (100 m²), *N* of 5 per treatment combination	Split-plot (fenced/unfenced): 2 whole plots, each with subplots of 25 m², *N* of 10 per treatment combination	Block: 10 blocks, 3 m²-sized plots, *N* of 10 per treatment	Block: 10 blocks, 20 m²-sized plots, *N* of 10 per treatment	Block: 3 blocks, each with 36 plots (49 m²), *N* of 6 per treatment
Response variables	Soil hydrological parameters (water content after a rainfall event at 10 cm, water storage at 5 cm depth), plant growth forms (preliminary assessment)	Plant growth forms (species richness, cover, abundances), chemical soil properties (pH, electrical conductivity, C/N ratio, total amount of nitrogen and carbon)	Plant growth forms, characteristic species of the quartz field, opportunists (species richness, cover, abundances)	Plant growth forms (species richness, cover, abundances),	Seedling emergence, seedling survival, natural recruitment of plant growth forms
Detailed description	Hanke et al. 2010, submitted	Meyer 2009	Etzold 2006, Meyer 2009, Meyer et al. in prep.	Etzold 2006, Meyer 2009	Simons & Allsopp 2007
Tested treatments					
Livestock exclusion	5 exclosures, each 1 ha	2 exclosures, each 0.25 ha	—	—	3 exclosures, each 0.25 ha
Brushpacking	*Brownanthus pseudoschlichtianus* (70% cover)	*Salsola* sp. (90% cover)	—	*Galenia africana* (90% cover)	*Galenia africana* (100% cover), applied alone and in combination with microcatchments
Dung mulching	Sheep and goat dung	Sheep and goat dung with palm fonds on top	—	—	—
Microcatchments	25 half-moon-shaped pits (10 cm deep, 40 cm wide and 60 cm long) per plot	—	—	—	12–16 triangular pits, (75 x 75 x 75 cm, 10 cm deep) per plot, applied alone and in combination with brushpacking
Functional plants	Transplants of *Brownanthus pseudoschlichtianus,* 20 individuals per subplot	—	Transplants of *Cephalophyllum spissum,* 20 individuals per plot	—	Already existing, naturally established individuals of *Galenia africana*
Stone applications	—	6 stone heaps (25 x 25 x 25 cm) per plot	Scattered quartz stones, 10% cover	—	—

Succulent Karoo

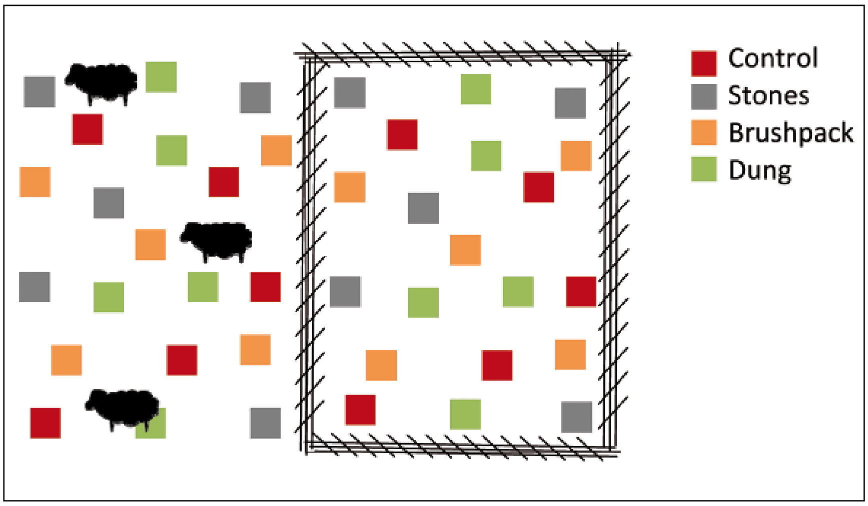


Fig. 5: Split-plot design at Soebatsfontein. The experimental site is divided into two plots of which one is fenced, while the other is grazed by livestock. Each plot contains subplots within which the active treatments were randomly allocated (modified from Meyer 2009).

Photo 15: Increased cover of the annual species *Foveolina dichotoma* in an exclosure one year after fence establishment in the communal rangelands of the Eksteenfontein village. Photo: Wiebke Hanke.

1–10 cm depth four years after the treatments were installed (Meyer 2009).

Paulshoek: In addition to the monitoring of natural plant recruitment, seeds and seedlings of palatable key species were introduced as indicators under the different treatments and their emergence and survival monitored monthly (Simons & Allsopp 2007).

Eksteenfontein: The evaluation focussed on soil hydrological parameters. The volumetric soil water content (at a depth of 10 cm) was recorded one year after the establishment of the treatment, just after a typical winter rainfall event (5.2 mm of fine drizzle, accompanied by cloudy, windy, and cool weather conditions). Additionally, soil water storage (at a depth of 5 cm) was monitored over 11 days after this rainfall event. Vegetation has not yet been statistically evaluated, but some obvious effects will be presented in a descriptive way (Hanke et al., submitted).

Knersvlakte: Prior to treatment application, the plots were cleared of invasive *Atriplex lindleyi* subsp. *inflata*, and the soil surface, which was heavily ripped from the pipeline construction work, was levelled (Photos 12–14). The evaluation of vegetation response included analyses with respect to two different plant species groups, namely: quartz field flora and opportunist flora (Meyer 2009, Meyer et al., in prep.).

Ecological concepts and results of the tested treatments

Livestock exclusion

Within (semi-) arid summer rainfall ecosystems, rest from grazing may induce recovery of perennial grass cover within less than a decade (Yayneshet et al. 2009, Kaouthar & Chaieb 2010). In the winter rainfall Succulent Karoo, however, grasses play a minor role and the time period needed for the recovery of shrub vegetation may be longer. According to recent studies from the Succulent Karoo, conducted after 40 (Haarmeyer et al. 2010) and 67 years (Rahlao et al. 2008) of resting, vegetation is able to recover to a pre-disturbance stage in the long-term. However, the triggering processes of autogenic succession, important for management decisions, still remain poorly understood. If livestock is removed, when and how is recovery induced? We therefore included livestock exclusion plots (Fig. 5) at Eksteenfontein and on the two farms at Soebatsfontein (Patrysegat and Quaggasfontein) in the restoration experiments (Table 5).

After one year of livestock exclusion in Eksteenfontein, soil water content at a depth of 10 cm was not significantly affected after the winter rainfall event (Hanke et al. 2010, submitted). This result was expected considering the short timeframe.

Chemical soil parameters were evaluated four years after fence establishment in the two exclosures at Soebatsfontein. The only parameters significantly affected were carbon and nitrogen. Both total carbon and nitrogen contents had increased by 20% in the exclosures on Patrysegat. The same trend was found at Quaggasfontein, but the difference between grazed and ungrazed plots was not significant. The mean C/N ratio on the farm Patrysegat was significantly higher in the exclosure (C/N ratio = 10.5) than outside (C/N ratio = 9.93), whereas the exclosure on Quaggasfontein showed the opposite trend, although this was not significant (Meyer 2009).

In both experiments, vegetation was affected by the exclusion of livestock and annual plant cover responded immediately to the release from grazing. The benefit that annual plant cover receives from being rested from grazing even for one year is clearly evident at the Eksteenfontein site (Photo 15). Also in one exclosure at Soebatsfontein (i.e. Quaggasfontein) four years after treatment application, the mean cover of annuals was more than twice as high inside the exclosure (7.84%) compared to outside (3.88%) where grazing continued with high intensity. The cover of perennial plants remained unaffected. Species richness of annuals and perennials increased significantly by 25% inside the exclosure. Compared to Quaggasfontein, on the farm Patrysegat grazing intensity adjacent to the exclosure was only of moderate intensity (Meyer 2009). Here the cover of annuals remained unchanged in the exclosure. The cover of perennials decreased significantly by 25% and species richness by 27% inside this exclosure.

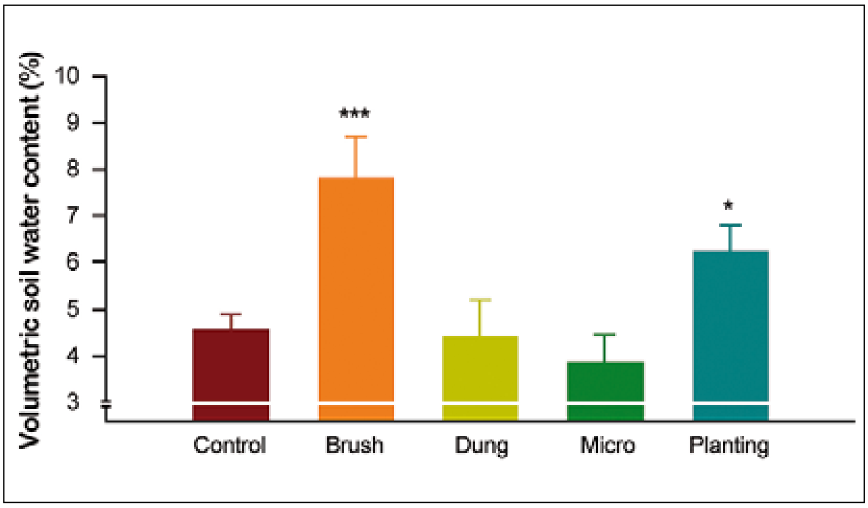


Fig. 6: Mean (+1 SE) volumetric soil water content after a rainfall event of 5.2 mm at Eksteenfontein. Asterisks indicate significant differences from the control derived from pairwise a priori comparisons following the analyses using linear models (*$p < 0.05$; ***$p < 0.001$), $N = 10$; Micro = microcatchment, Brush = brushpack.

Brushpacking

Brushpacks, which simulate the protective effect of the natural plant cover, have been successfully applied in (semi-)arid environments throughout the world (Coetzee 2005, Ludwig & Tongway 1996). Brushpacks protect the soil against erosion and solar radiation, and also improve soil moisture conditions. Unlike living vegetation, brushpacks do not compete for resources with other plants, but like them they may generate fertile islands by trapping soil particles or organic material and attract soil living organisms. Brushpacks were applied at all four restoration sites. The soil surface was covered with branches of indigenous shrub species covering 70–100% of the plots (Table 5).

Soil moisture measurements shortly after the winter rainfall event in Eksteenfontein (Fig. 6), showed that volumetric soil water content under brushpacks (7.8%) was higher than in the control plots (4.5%), and even exceeded the amount of water provided by the preceding rainfall event (5.2 mm). Prolonged

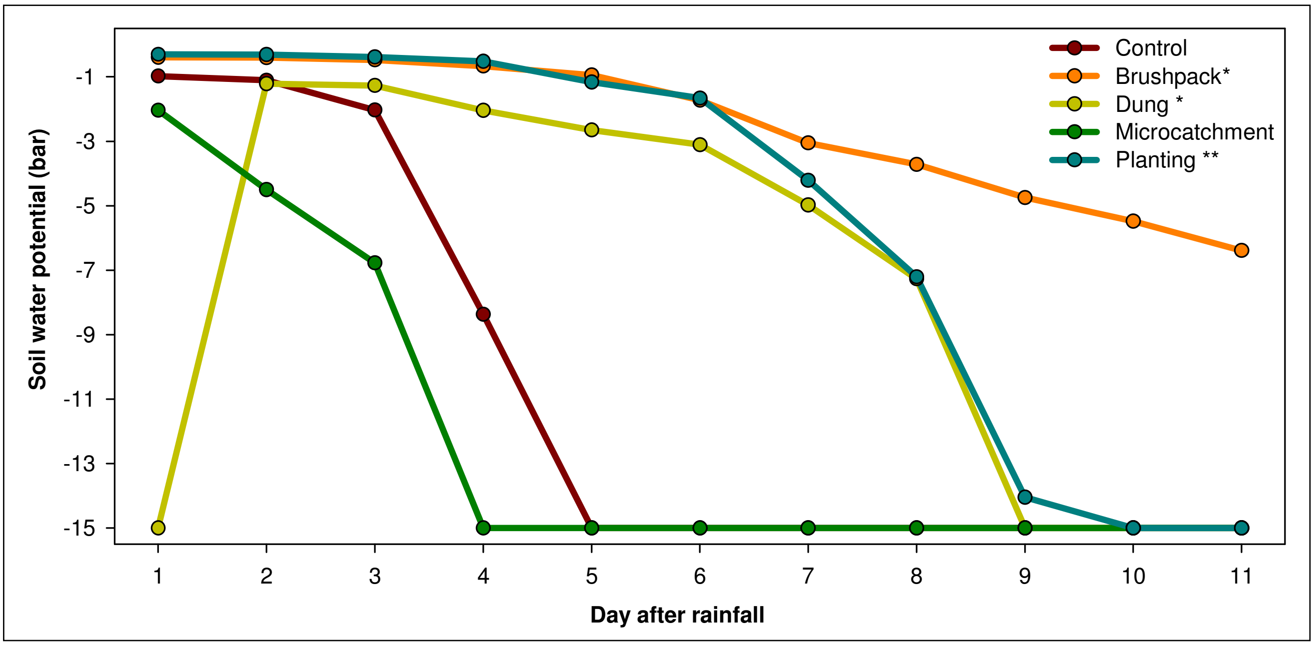


Fig. 7: Soil water depletion curves after a rainfall event of 5.2 mm. Data are medians of water potential over 11 days at 5 cm soil depth from gypsum block sensors (GB-1, Delmhorst Instrument Co.). Asterisks in the legend indicate significant differences from the control of treatment by time interaction (*$p < 0.05$, **$p < 0.01$), derived from nonparametric repeated measures analyses (Brunner et al. 2002). $N = 5$.

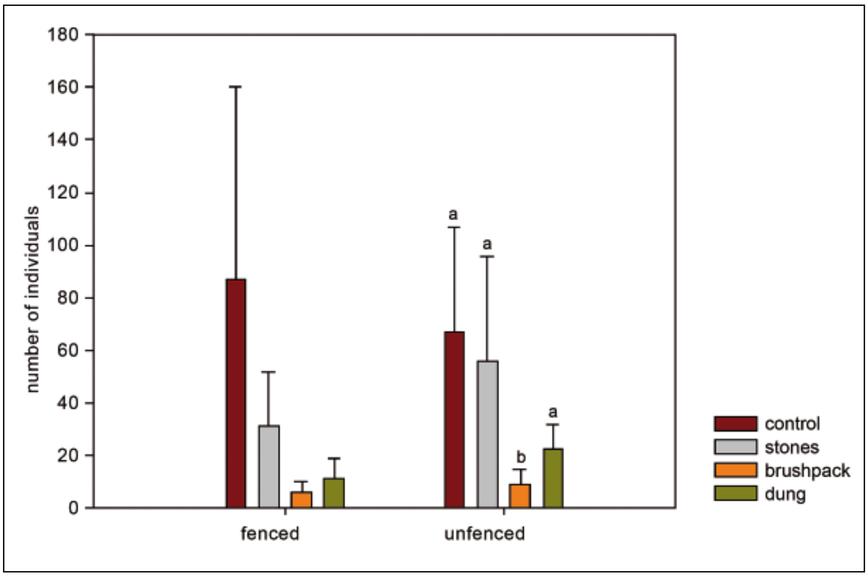


Fig. 8: Means (+SD) of the total number of perennials at fenced and unfenced subplots at Soebatsfontein on the farm Patrysegat in 2005, one year after installation of treatments. Different letters above bars indicate significant differences between treatments according to LSH with Bonferroni-Holm correction following Kruskal-Wallis tests.

water storage compounded this positive effect on soil water content. While soils of the control plots were desiccated to the permanent wilting point (–15 bar) at 5 cm soil depth within 5 days after the rainfall event, soils under the brushpacks did not reach the permanent wilting point within the 11-day measurement period (Fig. 7) (Hanke et al. 2010, submitted).

Soil parameters significantly affected by brushpacks in Soebatsfontein were soil pH and the total amount of carbon. On both farms, the mean soil pH under brushpacks (pH 6.98) was significantly higher than for the control plots (pH 6.70). Electrical conductivity values tended to be increased under brushpacks, but this trend was not significant. The total amount of carbon was significantly higher (up to 20%) under brushpacks on one of the two farms in Soebatsfontein (Patrysegat), reflecting the input of cellulose. On the other farm (Quaggasfontein), carbon values under brushpacks were also higher, but this trend was not significant (Meyer 2009).

The cover of ephemeral plants in the Knersvlakte one year after the installation of brushpacks was twice as high as in control plots (Meyer 2009). The cover of ephemerals was also increased by brushpacking at Paulshoek (Simons & Allsopp 2007), while in Soebatsfontein annuals remained unaffected (Meyer 2009). Perennial plant cover was not influenced positively at any site. At Paulshoek, brushpacks neither influenced the emergence of the introduced seeds, nor was it effective in promoting the survival of planted seedlings (Simons & Allsopp 2007). On one farm at Soebatsfontein, the abundance (Fig. 8) and species richness of perennial plants was actually impacted negatively by brushpacks (Meyer 2009). We assume that during treatment installation plant individuals were damaged through the spreading of the brushpacks.

Dung mulching

Positive responses of soil properties and plant cover have been demonstrated after mulching with different organic materials in various (semi-) arid environments (Zink & Allen 1998, Querejeta et al. 2000, van den Berg & Kellner 2005) and also in the Succulent Karoo using thatching reed (Beukes & Cowling 2003). We applied mulching with dung in the restoration trials at Soebatsfontein and Eksteenfontein (Table 5). Old sheep and goat dung from nearby stock post was spread onto the plots, so that 70–90% of the soil surface was covered by a thin layer. In Soebatsfontein the dung cover was stabilised using locally available palm fronds.

The dung cover had pronounced effects on soil water status, chemical soil properties and vegetation cover. The soil under dung had a lower water content than in the control directly after the rainfall event at Eksteenfontein (Fig. 7). It appears that some of the rainwater was absorbed by the dung before percolating into the soil. However, the 5.2 mm of rainfall was sufficient to saturate the dung and wet the soil, although soil-wetting was retarded. Once the water reached the soil, it was stored longer than in control plots, indicating the shading effect of the mulch (Fig. 7) (Hanke et al. 2010, submitted).

The chemical analyses of soil samples from Soebatsfontein revealed that the mean pH value was elevated from pH 6.7 in control plots to pH 7.3 under the dung on both farms. Mean electrical conductivity was increased on both farms by the dung, especially on Quaggasfontein, where the mean was five times higher under dung (237 µS/cm) compared to the control (52 µS/cm). Dung also significantly increased total nitrogen (up to 4 times) and carbon content (up to 5 times) compared to the control. C/N ratio decreased significantly on one farm (Quaggasfontein), whereas it was not affected on the other farm (Patrysegat) (Meyer 2009).

The cover of annuals increased at Eksteenfontein, especially the invasive species *Atriplex* spp. (Photo 16), of which the seeds were brought in by the dung (W. Hanke, University of Hamburg, unpubl. data). There was a similar trend at Soebatsfontein, but the increase of annual cover was only significant during the high rainfall year in 2006 (175 mm annual rainfall compared to a mean of 130 mm from 2001–2008). Species richness of perennial and annual plants was negatively impacted by the dung treatment in most of the years at Soebatsfontein (Meyer 2009).

Microcatchments

Soil surface structuring by microcatchments is widely and successfully applied for water and soil conservation throughout Africa (Critchley et al. 1994). Microcatchments were applied at the experimental sites at Paulshoek and Eksteenfontein (Table 5) in order to test whether they would improve the local accumulation of resources such as seeds, organic material and water, and thus enhance plant recruitment. Pits of 10 cm depth were dug at both sites, perpendicular to the general direction of water runoff. The pits were triangular (75 cm x 75 cm x 75 cm) at the Paulshoek sites, whereas they were halfmoon-shaped (40 cm wide and 60 cm long) at Eksteenfontein. Half of the microcatchments were combined with brushpacks at Paulshoek.

Soil water content in the pits shortly after the rainfall event was not significantly different from the control plots at Eksteenfontein (Fig. 6). The intensity of the typical winter rainfall event was apparently too low for the development of runoff. Soil water storage was not improved either (Fig. 7) (Hanke et al. 2010, submitted). Microcatchments also did not improve natural recruitment or the establishment of perennial seedlings and resulted in only a minor increase in the cover of ephemerals at Paulshoek. Controls showed better seedling survival than microcatchments. The poor seedling survival in microcatchments may be attributed to the removal of fertile topsoil when digging the microcatchments. Cover of geophytes was negatively affected, possibly because the digging of microcatchments uprooted the bulbs. The performance of microcatchments was not improved in combination with brushpack (Simons & Allsopp 2007).

Photo 16: Increased cover of the annual *Atriplex semibaccata* in a dung-treated plot at Eksteenfontein. Photo: Wiebke Hanke.

Functional plants

The fact that vegetation cover may positively affect soil properties and often facilitates the growth of other plants in drylands has been considered in the design of restoration measures (Padilla & Pugnaire 2006, King & Stanton 2008). Shrubs that crucially influence their surrounding environment are called ecosystem engineers (Jones et al. 1994). In the Succulent Karoo they create fertile islands by trapping wind-blown soil particles, seeds and organic matter (Stock et al. 1999, Anderson et al. 2004). Some species also function as nurse plants (Callaway & Walker 1997) in grazed systems, e.g. *Tripteris sinuatum* which forms positive associations with the refuge plant *Ruschia robusta* (Todd 2000).

Key species of the natural plant community were transplanted at two of the restoration sites: *Brownanthus pseudoschlichtianus* at Eksteenfontein and *Cephalophyllum spissum* on quartz fields in the Knersvlakte (Table 5). At the Paulshoek study site naturally established *Galenia africana* shrubs were tested for their potential as nurse plants.

After the 5.2 mm rainfall event in Eksteenfontein, the mean volumetric soil water content (7.8%) under the planted *Brownanthus pseudoschlichtianus* individuals was approximately one third higher than in the control plots (4.8%) (Fig. 6). In accordance with the result received for brushpacks, the water content exceeded the amount provided by the preceding rainfall event and this positive impact on soil water was enhanced by prolonged storage of soil water due to shading (Fig. 7).

Perennial cover was directly improved by planting, demonstrating the short-term success of this treatment. One year after transplanting, the *Brownanthus pseudoschlichtianus* transplants showed a survival rate of 71% and the *Cephalophyllum spissum* transplants showed a survival rate of 55%. Further monitoring revealed that although the number of *Cephalophyllum spissum* individuals decreased towards 2008, there were still on average nine times more *Cephalophyllum spissum* individuals present on the transplant plots compared to the control. The abundances of other plant species also increased significantly (Fig. 9) on the *Cephalophyllum spissum* transplant plots. Among these were opportunists as well as typical species of undisturbed quartz field vegetation. The planted seedlings underneath the canopies of naturally established *Galenia africana* shrubs at Paulshoek showed higher survival rates at two out of three restoration blocks compared to the other treatments and the control (Simons & Allsopp 2007).

Stone applications

Stones are normally used for restoration purposes in gullies or on slopes as a barrier against erosion (Critchley 1994, Coetzee 2005), but landusers in the Succulent Karoo have also observed additional positive effects of stones (Botha et al. 2008). Soils that have small stones or rocks on the surface are less prone to drought-induced plant mortality. Stones further reduce wind speed and catch wind-blown seeds, soil particles, and organic material. Thus, stones might fulfil similar functions as brushpacks, but require no harvesting of plant material.

Stone treatments were applied at Soebatsfontein and in the Knersvlakte (Table 5). At the Soebatsfontein experiments six stone heaps (approximately 25 cm x 25 cm x 25 cm) per plot were installed. On the quartz field site in the Knersvlakte, we tried to reconstitute the situation prior to the disturbance. Quartz stones (6–20 cm

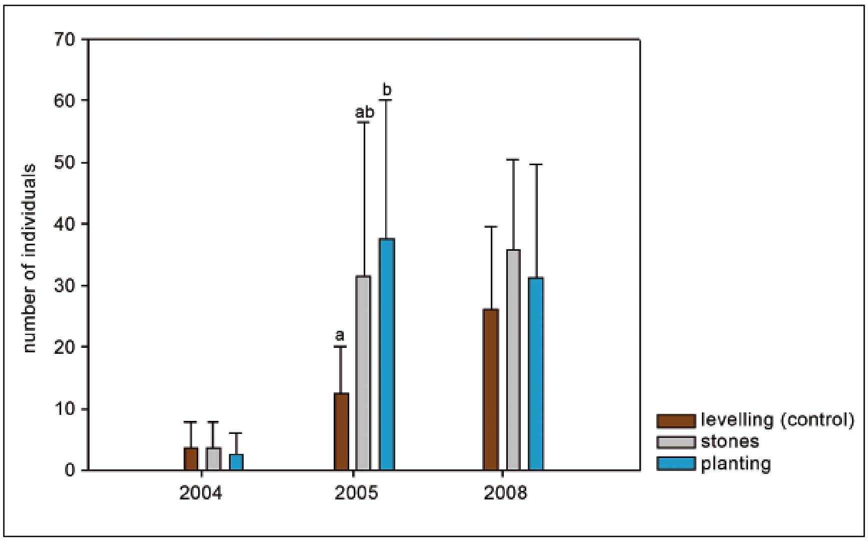


Fig. 9: Means (+SD) of the number of all plant individuals on restoration plots in quartz fields (*Cephalophyllum spissum* community) in the Knersvlakte. A treatment effect was indicated by Kruskal-Wallis tests for the mean number of individuals in 2005. Different letters above bars indicate significant differences between treatments according to LSH with Bonferroni-Holm correction.

in size) were evenly scattered, covering about 10% of the soil surface.

The soil and vegetation variables examined at the stone treatment plots did not differ from those at the control plots at the Soebatsfontein site (Meyer 2009). Positive effects on the vegetation were observed four years after the introduction of the quartz stones on the quartz fields of the Knersvlakte. The number of plant individuals, including both opportunists and obligate quartz field taxa, increased significantly when compared to the control plots in 2005 (Fig. 9). However, the significant effect ceased towards 2008 (Meyer et al., in prep.).

Understanding the processes of vegetation recovery

Background

We collated the results of the four restoration experiments described above. The fact that the experiments were conducted at different places and over different years offers the opportunity to identify some principle restoration requirements for degraded Succulent Karoo rangelands. The variety of measured soil and vegetation parameters provides insights into the processes, which determined treatment performance.

Growth form

Annuals responded more strongly to the treatments than perennials. Only two of the restoration treatments had an unambiguously positive influence on the perennial vegetation cover: the scattering of quartz stones on disturbed quartz fields; and planting, where perennial cover was directly improved through the transplants. However, the cover of annual species was promoted by four treatments: livestock exclusion, dung mulching, scattering of quartz stones, and to a certain degree also by brushpacking. The stronger response of annuals compared to perennials may be attributed to their opportunistic nature (Lavorel & Garnier 2002), their higher abundance in the seed bank (de Villiers et al. 2003) and, in the case of mulching, to the abundance of their seeds in the dung. The assumption of de Villiers et al. (2003), who studied soil seed banks in the Strandveld Succulent Karoo, that successful restoration will often require the reintroduction of perennial plants is confirmed by our results.

Spatial and temporal scale of degradation

Restoration efforts on the pipeline in the Knersvlakte showed clearer success than those in the overgrazed rangelands. The pipeline installation only disturbed a small strip, whereas the rangelands have been disturbed over an extensive area. Our results thus confirm that small-scale degradation is easier to restore than large-scale degradation. In a review on mine spoil restoration in the Succulent Karoo, Carrick & Krüger (2007) mention several reasons for this. Most importantly, large-scale disturbances only have a small contact zone with the surrounding vegetation and thus lower probability of seed input. Furthermore, the lack of vegetation on large areas causes higher wind speeds. The few seeds that blow into the area are not readily trapped, and therefore the chances of establishment are lower. Higher wind speeds also inhibit plant recruitment because they result in greater erosion rates of fertile topsoil.

In addition to the spatial scale of degradation, the temporal scale might also have influenced the success of restoration, particularly in the Knersvlakte. The pipeline restoration experiment in the Knersvlakte started only four years after the initial disturbance, whereas for the other sites, overgrazing had occurred for decades prior to the studies being conducted. The fundamental soil properties were probably less affected in the Knersvlakte and the soil seed bank may still have contained some of the species, which were present in the former, undisturbed vegetation.

Soil hydrology

Degradation of (semi-) arid rangelands increases water stress for plants in an environment where water is the limiting factor for plant growth even under undisturbed conditions. The increase of water supply for plants by improving the soil water status is therefore of major concern for restoration success (Thurow 2000). The Eksteenfontein experiment showed that soil water content directly after a typical rainfall event was considerably increased under planting and the application of brushpacks. Storage of soil water was improved by planting, brushpacks, and dung. For microcatchments no effect on soil water was detected.

In dry ecosystems, the net input of rainwater into the soil is determined by canopy interception and the partitioning of infiltration rate and runoff (Loik et al. 2004). Soil water under the transplants and brushpacks even exceeded the water amount provided by the preceding rainfall event. The rainfall followed a six week dry period and the upper soil was probably similarly desiccated under all treatments prior to the event. It is hence likely that brushpacks and planting somehow increased the water input during the rainfall. Since the rainfall event was associated with strong winds, we suggest that the branches 'combed out' raindrops from the air and water was thus concentrated and accumulated in the soil below. The capturing of raindrops may lead to evaporation losses of the intercepted water from the canopies (Dunkerley 2008), unless air temperatures are sufficiently low to retard evaporation rates (Loik et al. 2004). In winter in the Succulent Karoo, evaporation losses from the canopies are probably of minor relevance, because the winter rainfall derives from coastal lows (Desmet & Cowling 1999) with weather conditions during rain gaps and shortly after the rainfall event usually being cloudy, cool, and humid. The amount of gathered rainwater channelled to the soil below also depends on the canopy architecture (Mauchamp & Janeau 1993, Domingo et al. 1998, Dunkerley 2008). Apparently the succulent, cylindrical internodes of *Brownanthus pseudoschlichtianus* channelled the water effectively.

In regions where intense, erosive rainfall events are prominent during the growing season, manipulations to prevent or capture runoff are key measures for restoration processes (Critchley et al. 1994). However, microcatchments did not impact soil water content showing that during this low-intensity rainfall event, runoff was of minor relevance (compare Li et al. 2005).

In general, the results suggest that the spatial distribution of water input into the soil was influenced by processes related to canopy interception rather than by the partitioning of runoff and infiltration during the typical winter rainfall event. However, although a large portion of water input during the growing season in the Succulent Karoo results from small, low-intensity rainfall events (Desmet & Cowling 1999), microcatchments could be effective during strong rainfall events typical of thunderstorms during summer. Although rainfall outside the growing season is not likely to promote seedling germination or establishment of perennials (Esler 1999), it could enhance the survival and growth of established plant individuals.

All treatments that shaded the soil surface and protected the soil surface from wind (i.e. transplants, brushpacks, and dung) had a positive effect on soil water storage. After winter rainfall events, day temperatures may increase considerably within a few days, leading to rapid evaporation of soil water. This is compounded by the shallow percolation of rainwater after low-intensity rainfall events (Francis et al. 2007). Under these conditions, protective cover of the soil surface is a crucial factor for water retention. The improved soil water conditions under dung mulch, brushpack, and functional plant treatments may be one factor responsible for the enhanced plant growth recorded under these treatments. However, rainfall amount remained the limiting factor. Dung promoted growth of annuals only in good rainfall years, which could be explained by the observation that the rainwater first had to saturate the dung layer before entering the soil.

Low rainfall was probably the main reason that only 90 seedlings out of the 20,000 seeds sown at the Paulshoek restoration trial emerged, irrespective of the accompanying treatments (Simons & Allsopp 2007). Planting was more successful than sowing. Apparently the transplants, in both cases succulent shrubs, could cope well with little rainfall. One year after transplanting, the survival rates of *Cephalophyllum spissum* and *Brownanthus pseudoschlichtianus* were 55% and 71% respectively, which is remarkable considering that poor rainfall conditions that followed transplantation.

Chemical soil properties

Significant effects regarding chemical soil properties were detected for those treatments, which were associated with the introduction of organic matter. The organic input from dung and brushpacks was reflected by an increase of carbon in the soil. The fact that livestock exclusion also increased the amount of carbon indicates that litter accumulated after grazing was stopped (compare Allsopp et al. 2007a). Nitrogen was elevated after livestock exclusion and dung input, and dung also decreased the C/N ratio. The increase of nitrogen after livestock exclusion could have partly arisen from the accumulated litter. However, a second process, which can be explained by the nitrogen loss hypothesis, might have contributed to the increase of nitrogen in the exclosures. Grazing increases the removal of nitrogen out of the system because dung and urine concentrate the nitrogen on small patches around stock posts and water points where it is partly lost through volatilisation or leaching (Pineiro et al. 2009, Hiernaux et al. 1999).

The increases of carbon and nitrogen in response to dung treatment was stronger than in response to the accumulated litter in the exclosures or to brushpack, which reflects the different properties of the input materials (compare Mokolobate & Haynes 2002). Dung possesses a higher mineral content and a lower C/N ratio. Dung also increased pH and electrical conductivity considerably, while the effects of brushpack on these variables were less pronounced. The increase of pH after treatment with dung or plant residues concurs with studies from other parts of the world (Mbagwu 1992, Tongway & Ludwig 1996, Wong et al. 1999, Whalen et al. 2000, Mokolobate & Haynes 2002). This can be explained by alkalizing components, such as $CaCO_3$ or Na and by the proton consumption capacity of the humic material present in the dung and plant residues (compare Mokolobate & Haynes 2002).

The increase of electrical conductivity after dung treatment also concurs with findings of Mokolobate & Haynes (2002), who showed increased levels of exchangeable Ca, Mg, K, and Na after the application of poultry dung. In (semi-) arid rangelands, the forage resource includes halophytic plants (Ward 2009) and the salt content of dung is therefore often particularly high. An increase of soluble salts in the soil is of potential concern in arid environments and dung should not be applied to soils prone to salinisation. Areas of concern in the Succulent Karoo are, for instance, fine-textured soils typical for the Knersvlakte (Francis et al. 2007) or calcareous and gypsum-rich pans. Soils of the study site at

Soebatsfontein are less prone to salinisation, because the high sand content guarantees good drainage and thus prevents accumulation in the upper soil layer. The values after dung treatment did not indicate strong soil salinisation and total plant cover was, in fact, greatest for the dung treatment in our experiments. However, the elevated electrical conductivity might have contributed to the negative influence on species richness. It seems that salt-tolerant ephemerals, especially *Atriplex* spp., benefitted and had an advantage over other species (compare de Villiers et al. 1992). Also, the nitrogen fertilisation from the dung might have enhanced the growth of *Atriplex* spp. and other fast-growing ephemerals, as high nutrient availability supports species with rapid resource allocation and rapid turnover of organs (Grime 1979).

Plant interactions: competition and facilitation

Besides the manipulation of the growing conditions, treatments also induced changes in the vegetation cover, which appeared to have further impact on plant growth, involving both, competition and facilitation. Competitive interactions between the species were probably manipulated by the exclosures in Soebatsfontein. Species richness was increased by rest from heavy grazing, but decreased in response to rest from moderate grazing. This is in line with the intermediate disturbance hypothesis (Grime 1973, Connell 1978). According to this hypothesis, moderate disturbance increases the competitive interactions between species, which affects species richness positively. Only under severe disturbance is biodiversity expected to decrease.

Among the active treatments, dung appeared to have the greatest impact on competitive interactions between growth forms. Although soil properties were enhanced in terms of nitrogen and water supply at the dung plots in Soebatsfontein, the establishment of perennial species was not supported and their richness even reduced. This may be due to competition with invasive *Atriplex* spp., which spread in response to dung treatment and may have negatively affected the establishment of perennials. Also, the enhanced performance of the treatments in the Knersvlakte could be related to this issue. Here, all plots were cleared of the opportunistic species *Atriplex lindleyi* subsp. *inflata* before treatment establishment. This may be a reason why key perennial species of the quartz field flora could recover well. Competition from annuals has been shown to increase the mortality of seedlings of perennial plants under arid conditions (van Epps & McKell 1983). By contrast, annuals had no detectable effect on the seedlings of perennials in a clearing experiment in the southern Karoo, which borders the Succulent Karoo (Milton 1995). However, we assume that in the case of opportunistic *Atriplex* spp., which tend to form a relatively dense cover, the recovery of the shrubby vegetation is hampered. On the other hand, the establishment of annuals or fast growing, opportunistic perennials could protect the exposed soil, and may in time add to the organic matter of the soil and thus trigger a succession towards long-living species. Continued monitoring of the experiments will show if annual cover facilitates an increase in perennial plant cover or not.

The experiments also revealed several facilitative effects of perennial plant species themselves. The abundance of other plant species increased significantly along with the planting of the perennial *Cephalophyllum spissum* individuals. The nurse plant experiments with *Galenia africana* also showed that conditions under the shrubs supported seedling establishment and improved the survival of perennial plants (also compare Gabriels et al. 2003) since it possibly provides nutrient-enriched soils (Allsopp 1999b), protection from climatic extremes and enhanced soil moisture. On the other hand, *Galenia africana* might have competitive impacts on the seedlings that it nurses as they grow. Several studies in arid ecosystems have demonstrated that seedling establishment and survival were greater underneath the canopies of shrubs than in the open spaces between shrubs (Callaway & Walker 1997). According to the stress gradient hypothesis it is assumed that competition becomes less important and facilitation relatively more important in drylands, since abiotic conditions are harsh (e.g. Callaway & Walker 1997). However, a study in the Succulent Karoo demonstrated that facilitation appears to play a less important role (Carrick 2003). Future revisits of the experiments could help to better understand the interplay between competition and facilitation in Succulent Karoo rangelands.

Implications for further research

Restoration of degraded rangelands in the Namaqualand, as part of the Succulent Karoo Biome, is still in its pioneer phase. The broad range of basic ecological research as well as the various restoration trials conducted over the last decade have significantly contributed to an understanding of the ecosystems of the Succulent Karoo. However, there are many important aspects that are still not clearly understood, as has been shown by the integrative analysis of the four restoration studies in this Subchapter.

This analysis that went beyond the scope of a single case study identified some abiotic and biotic processes that seem to drive the dynamics in restoration trials. The responses of opportunistic plant species, for instance, have been related to treatment effects on soil properties. However, the responses of long-lived shrubs, that characterise intact Succulent Karoo rangelands, were less pronounced. Continued monitoring will show whether the enhanced emergence of opportunistic species, which especially followed the dung treatment, will support or inhibit the recovery of key, perennial shrubs. The data will thus provide insights into the important competition and facilitation processes among different plant strategy types and contribute to a general understanding of ecological processes in the Succulent Karoo Biome. The monitoring of the exclosures would also help to identify the appropriate resting periods required for vegetation recovery, which is important information required for the development of appropriate and effective rangeland management strategies. Future research should also test some modifications of the trails that have been described in this Subchapter. The brushpacking technique, for instance, should be further refined by comparing different densities and techniques of packing (e.g. brushpack islands of varying sizes).

For the application of restoration in practice at larger spatial scale (i.e. at stock post-, camp- or even farm-scale), quantitative aspects of practicability as well as cost and benefit have to be included in future evaluations. The aspects of practicability and costs comprise monetary expenses as well as availability of natural and human resources. The benefit aspects comprise the immediate monetary benefit of restoration through improved rangeland but should also consider the improved or enhanced ecosystem services that are provided by the restored ecosystems. The socio-economic benefits of ecological restoration are critical for their societal and political appreciation and support. However, they are hardly adequately quantified in respective studies (Aronson et al. 2010).

Every future ecological-economic evaluation of restoration trials and emerging recommendations should be aware that besides the described particularities of the Succulent Karoo, the biome is extraordinarily heterogeneous. As has also been shown by this study, the various habitats, driven by a high diversity of topography, soil types, rainfall patterns, floristic inventories, historical and recent landuse, etc. also respond differently to restoration measures.

Implications for restoration practice

The evaluation of the restoration experiments outlined in this analysis has opened new insights into the treatment effects on soil properties and vegetation. But what are the practical implications for restoration projects in degraded rangelands of the Succulent Karoo? What is the appropriate treatment and how can restoration success be optimised in the field? Beside resource availability in terms of manpower and materials for treatment installation and maintenance, the findings of this article suggest several factors that should be considered:

Scale of disturbance

- In case of the small-scale disturbance due to the pipeline construction on quartz fields, the application of stones is sufficient, considering cost-effectiveness and long-term effects. Perennial plants may spread into disturbed areas from the surrounding vegetation by themselves.
- In contrast, the restoration of large-scale degradation will often require the reintroduction of key perennial species. Transplanting of mature individuals proved to be more successful than sowing. Transplants with succulent leaves have a good chance of survival, since they are drought-adapted. Transplants might be the only palatable species within a vast area and protection from selective grazing using fences would therefore aid in restoration success.

Habitat characteristics of the focal system

- Considering the characteristics of the winter rainfall regime in the Succulent Karoo, it is recommended to manipulate canopy water 'combing' and soil shading rather than runoff related processes for the improvement of water supply during the growing season.
- Treatments that tend to increase salt content of the soil (i.e. dung), should be applied only after ensuring that the respective soils are not prone to salinisation.

Degradation level and restoration objectives

- In cases where the target system is in a less degraded state, in which vegetation cover of an early successional state still occurs, restoration measures would aim to reconstitute a diverse succulent shrub community. If financial and labour resources are available, the introduction of the respective key perennial species is recommended.
- The situation is different when it comes to restoring rangelands where bare soil patches predominate on a large scale. In such cases it may already be a satisfactory achievement to cover the soil with vegetation, even if it is only by opportunistic species with an annual life cycle. Dung could be an appropriate, cost-effective treatment, which is easy to install in such a situation. The effects of brushpack were less pronounced but it can also increase ephemeral plant cover. We suggest avoiding destructive installation effects by creating a thinner, patchier layer of brushpacks, which allows enough light to penetrate and leaves more space for plants to establish. The spatial arrangement of brushpacks should consider that the lee side might receive less precipitation due to a 'rain-shadow' effect.

4.5 Land management in the biodiversity hotspot of the Succulent Karoo. A case study from Soebatsfontein, South Africa

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Introduction

Soebatsfontein is a small rural settlement in the Namaqualand lowlands of the Succulent Karoo biome, an area, which is widely acknowledged as a centre of biodiversity and endemism (Myers et al. 2000, Mucina et al. 2006). The Soebatsfontein commonage has experienced a transformation of tenure and management over the course of recent political changes in South Africa. As part of post-apartheid land and agrarian reform, 15,069 hectares of farmland were transferred from the private De Beers mining company to the rural Soebatsfontein community, which until the year 2000 did not have any access to farmland. The communal farming area is referred to as "new-commons" and is characterised by a subdivision of the land into several camps and the allocation of these camps to farmers within the community. While the community members have usage rights, the land is formally owned by the local municipality of Kamiesberg.

One of the central aims of this land reform was to support the subsistence livelihoods of the community by enabling them to farm with small livestock. The farmland, comprising 15,069 hectares of land, is relatively small compared to the number of households that are in need of additional sources of income (the size of an average commercial farm that is owned by one family is about 5,000 hectare). When the community received the farmland, some of the camps were in relatively poor condition and they were therefore left to rest for some years in order to enable vegetation recovery. This management decision was economically unproblematic for the farmers as the stocking density on the rangelands was comparatively low during the first two years due to a lack of financial capital and the time required for the herds to grow. From the outset, the farmers in Soebatsfontein were aware of the widely held prejudice that communal farmers always let their farmland degrade. Several of the Soebatsfontein farmers therefore aimed to disprove this stereotype by trying to manage the land sustainably. The existence of camps and their clear allocation to individual farmers seemed to be in favour of this aim. However, management of the Soebatsfontein commonage during the first decade faced social and economic challenges, which were exacerbated by the arid environment.

Socio-economic studies within BIOTA Southern Africa aimed to understand the socio-economic framework under which the community members of Soebatsfontein manage their farmland. The mapping of soils, biological soil crusts, and vegetation aimed to: a) provide baseline data for farm management in Soebatsfontein, which could also be used as benchmark data for future assessments, and b) assess the impacts of the historic (during De Beers ownership) versus current grazing management.

Soil patterns, distribution, and states are, together with the topography, the main drivers of vegetation composition in a given climatic zone. In Namaqualand, the patchiness of soils at different spatial scales has been shown to strongly influence species composition of the vegetation (Herpel 2008, Schmiedel & Jürgens 1999, Subchapter IV.4.2), thus contributing to the exceptionally high species richness of the Succulent Karoo. Soils, in return, are also influenced by biotic interactions, i.e. burrowing insects and mammals (Lovegrove 1991, Picker et al. 2007, Petersen 2008) and, less obviously so, by the plants themselves (Hook et al. 1991, Stock et al. 1999). The water-holding capacity, nutrient content, and other chemical and physical features of soils, which may be altered by local vegetation patterns may, in turn, influence the density, structure, height and thus quality and quantity of plant biomass in the area.

Biological soil crusts, formed by an association of the uppermost layer of the soil with cyanobacteria, algae, bryophytes, lichens, microfungi, and heterotrophic bacteria in varying proportions, occur worldwide in arid and semi-arid regions and wherever an arid microclimate occurs (Belnap et al. 2003a, Article III.3.4). Due to the agglutination of soil particles by the gelatinous sheaths of cyanobacteria they effectively prevent soil erosion by wind and water (Belnap & Gardner 1993, Belnap 2002a). They also enrich the soils with nutrients and increase their water-holding capacity (Belnap 1995, 2002a, Belnap et al. 2003b, Jafari et al. 2004), thereby promoting plant establishment and growth. However, biological soil crusts are very susceptible to disturbances caused by different kinds of landuse (Belnap & Gardner 1993, Belnap 1995) and can therefore be employed as sensitive indicators of the effects of current landuse on the soil.

The first part of this section provides insights into the socio-economic conditions that influence management decisions on the Soebatsfontein commonage. The second part describes the diverse natural environment and tries to disentangle the impact of present versus pre-communal grazing management on the biodiversity of the farmland. To conclude, we discuss the perspective for future land management in Soebatsfontein.

Material and methods

Socio-economic studies

BIOTA Southern Africa carried out several socio-economic studies within the Soebatsfontein community (Falk 2008, Linke 2009, Vollan 2008, 2009). Linke (2009) conducted an ethnographic census, gathered qualitative data on local knowledge and small stock farming, and monitored landuse activities over a period of five months. In her case study she analysed the links between features of the community and the pastoral land management system. Falk (2008) assessed the availability of natural, human, financial, physical, and social capital as preconditions for resource management. Based on an interview survey, he further analysed the framework of formal and informal resource management institutions. Vollan (2009) examined norms of trust and trustworthiness (i.e. reciprocity) in southern Namibia and Namaqualand. Norms of reciprocity to a large degree explain why people co-operate (i.e. they only co-operate if others also co-operate). To elicit the crucial norms of trust and reciprocity, a standard experimental procedure was followed (Berg et al. 1995).

Sampling and analysis of soil and vascular plant patterns

The communal land of the Soebatsfontein region is subdivided into 17 camps, which are separated by fences. We classified the camps into three categories (low, intermediate, high, Fig. 10) according to their grazing intensities between 1986 and 1999 during management by the De Beers Company (hereafter referred to as historic grazing intensity). We overlaid high resolution satellite images (Digital Globe, 11/2003, provided by Google Earth) of the commonage and the adjacent farms with a 300 m x 300 m grid. The more than 4,000 resulting grid points were classified into ten categories according to geomorphological, geological and substrate properties, as well as historical grazing intensity classes per camp.

A random selection was drawn from among the 4,000 grid points with four replicates for each historical grazing intensity class for soil-profile and vegetation sampling (90 profiles and relevés), 10 replicates for vegetation and soil-surface sampling (in total 107 relevés), and 30 replicates (10 replicates per historic grazing intensity class) for vegetation and soil sampling on heuweltjies (total of 121 relevés). The study area was assessed in terms of historical grazing intensity classes using the following data and calculations (Labitzky 2009):

- ‘Total cumulative sheep grazing days’ were calculated based on the cumulative number of animal days per camp (data kindly provided by Mr. F. Brandt, the former farm manager for De Beers).
- For the ‘actual sheep grazing days’ the ‘total cumulative sheep grazing days’ were averaged over the recorded years.

- The 'potential sheep grazing days' were calculated based on an assumed carrying capacity of 9 ha per SSU (i.e. one adult sheep or goat) by applying the following equation: (Area/Carrying capacity) x 365 days.
- Camps that were used for over 120% of the 'potential sheep grazing days' were classified as grazing intensity class 'high' = 3. Those used for 80–120% 'potential sheep grazing days' were classified as 'intermediate' = 2, and those camps used for less than 80% 'potential sheep grazing days' were classified as 'low' = 1.

The recent landuse intensity classes were classified according to the 'actual sheep grazing days' recorded for 2007 (R. Christiaan, unpubl. data) and relating them to 'potential sheep grazing days' per camp (Röwer 2009).

Each soil profile was sampled and analysed according to the KA5 (AG Boden 2005). A soil sample (about 600 g) of each horizon and the topsoil was taken for laboratory analysis and the soil was classified according to the World Reference Base for Soil Resources (2006). Using SPSS for Windows 15.0 (SPSS Inc.), the influence of landuse and land type on soil properties was analysed. A detailed description is given by Labitzky (2009).

All occurring vascular plant taxa were listed and their percentage cover estimated for each plot. The nomenclature of vascular plants follows Hartmann (2002a, b) for the Aizoaceae and Germishuizen & Meyer (2003) for the remaining taxa. Total cover of mosses and biotic crusts, including other bryophytes, were also estimated. We clustered the relevés into distinct vegetation units using numerical classification methods (Luther-Mosebach 2009). Vegetation relevés of the heuweltjie centres were analysed using multiple linear regressions with historical and recent grazing intensities (square root transformed) and topography as predictors and a set of soil chemical, vegetation and structural parameters as response variables (Appendix 1).

BIOTA installed two grazing exclosure fences (each 50 m x 50 m) for restoration experiments (Subchapter IV.4.4) in two different camps of the Soebatsfontein commonage. The areas surroundings the two exclosures were subjected to different grazing intensities. We sampled the abundance and projected cover of vascular plant species at 20 plots (5 m x 5 m) each outside and inside the grazing exclosures four years after installation. For this study, we analysed various vegetation parameters (i.e. annual cover, perennial cover, total vegetation cover, and species richness) in the control plots that were not treated with restoration measures inside and outside the exclosure (Meyer 2009). Differences between values were analysed using ANOVA.

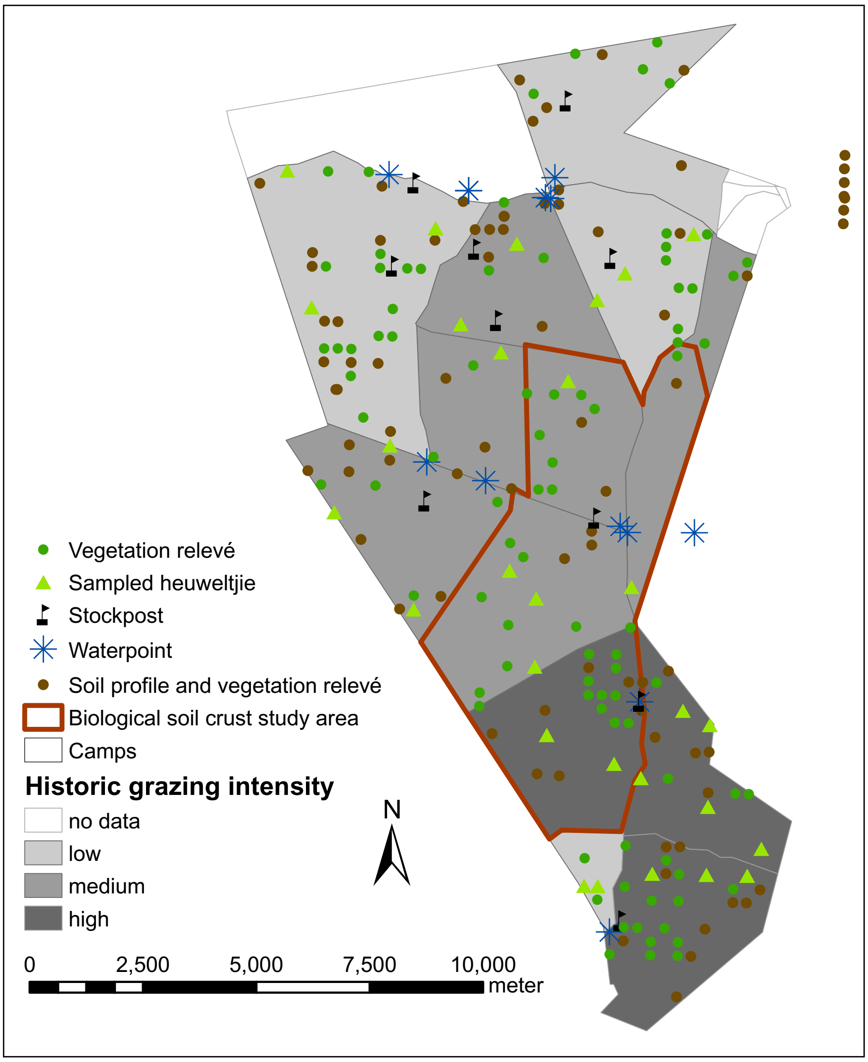

Fig. 10: Historical grazing intensity classes per camp and the distribution of plots for vascular plant relevés on the Soebatsfontein commonage.

Sampling and analysis of biological soil crusts

Sampling of biological soil crusts (BSC) was conducted on 60 plots (5 m x 5 m) located in the exclosures and on four different camps within the commonage (Kateklip, Kruisvlei, Rooshogte, and Langkamp). A 25 cm x 25 cm grid was randomly placed at six points and mean BSC coverage values in each plot were determined using the point-intercept method described by Belnap et al. (2001). We distinguished between initial BSC, formed by cyanobacteria that cause a patchy discoloration of the soil (type 1; Büdel et al. 2009 and Article III.3.4), and climax BSC, consisting of well established cyanobacterial mats, as well as bryophyte (moss) and lichen dominated BSC (types 2–5, Büdel et al. 2009, Article III.3.4). Local utilisation of each plot was estimated by counting sheep and goat faecal pellets within each grid. As a second grazing related parameter, the distance of each plot to the next stock post or watering point was measured using a Geographical Information System (GIS; ArcView 3.2, ESRI, Redlands, USA). For this, the route most likely taken by

Photo 17: Soebatsfontein settlement, 2004. Photo: Ute Schmiedel.

the animals was considered. For plots located in the exclosures, the distance to the next stock post or watering point was set to 4,000 m (the greatest distance within a grazed camp was 3,262 m). All statistical analyses were carried out using SPSS (SPSS 15.0 for Windows, SPSS Inc., Chicago, USA).

Results and discussion

Social and economic factors and norms of trust and cooperation as framework conditions for management decisions in Soebatsfontein

Social and economic factors: The Soebatsfontein community has approximately 270 inhabitants that live in 60 households (unless stated otherwise, data in this chapter are based on Linke 2009). Today, the community comprises a few large family groups, which are closely related through marriage. Before the apartheid era, the 'coloured' families worked and lived dispersed on the surrounding farms. During the 1950s, these families had to move to a small area owned by the church, which was declared the 'coloured' settlement of Soebatsfontein (Photo 17).

Since then the population of Soebatsfontein has experienced a substantial fertility decline, even though the community increased in numbers, especially during the 1970s and 1980s. As the observed growth cannot be just a natural one, immigration must be taken into account. During the 1970s and 1980s, two larger family groups, amongst others, immigrated to the area due to job opportunities on the surrounding farms. Nowadays, a rapid increase in the Soebatsfontein population is highly unlikely, and neither natural population increase nor immigration can been seen as crucial factors affecting land management. Nonetheless, immigration has significantly shaped the social organisation of the community. The two above-mentioned families are distinguished from kin groups who have lived within the community for several generations (the "original" community). Although incoming families are nowadays well linked through marriage relations with long-established families, there are still tensions between them. A major reason for this is that the incoming families are perceived to be economically more successful. The ethnographic census showed that households with higher and more stable livelihood income sources are often those of immigrant families, whereas most of the low income households are 'originally' from the village. However, it should be noted that there are also some exceptions to this pattern.

Living in nuclear families, with the majority of household members belonging to the core family, is the norm in Soebatsfontein. New households are usually formed after marriage. Quite a few children are born out of wedlock and are raised in the parental home of the mother until she marries. The average household size is 4.6 persons.

Livelihoods in Soebatsfontein are typically diversified and household members are involved in different economic activities. This has also been described for other rural communities in Namaqualand (Berzborn 2007) and Namibia (Schnegg 2009). Wage labour, state pensions and retirement benefits from the De Beers pension fund are the main sources of income, whereas livestock farming contributes mostly to subsistence. In about 60% of all cases in Soebatsfontein, monthly household income is low (< 120 US$/household) and insecure. The majority of household members are temporarily employed and pensions or retirement benefits are often the only regular sources of income. Households that are dependent solely on short-term work are the most vulnerable and poorest in the community (about two-thirds of low-income households).

One of the few opportunities for community members to obtain permanent employment is to work at one of the diamond mines along the west coast of South Africa (e.g. Kleinsee or Koingnaas). In 2005, about 40% of the households in Soebatsfontein derived income from a permanent work position or relied on a combination of regular income from state pensions and retirement benefits. These households are economically stable and the average per capita income is at least three times higher compared to those with an insecure work status. About one third of households own small stock (sheep and goats), which provides them with milk and particularly meat. Only a few farmers earn cash from larger livestock sales. However, livestock farming is becoming an increasingly important activity in the area as mines are closing down in the region.

Norms of trust and cooperation: In Soebatsfontein, farmers collectively own infrastructure, such as fences, pipes, and wind pumps that have to be maintained, and there is also the daily need of borrowing tools and vehicles for transportation. There is therefore a need for co-operation between community members in order to cope with the restricted, jointly used resources. In order to assess whether these and other interactions in their everyday lives are based on mutual trust and cooperation, several economic field experiments were carried out (Article III.6.5). The experiments revealed that levels of trust are extremely low in Soebatsfontein, and in many other more traditional farming communities of Namaqualand, compared in particular to the results of the same experiment in southern Namibia, where cultural norms are still more prevalent. The general interpretation from trust games is that the weak performance of trust can be attributed to weak local institutions that do not prevent free-riding and untrustworthy behaviour, so that this behaviour prevails in a society. According to this view, local institutions in Namaqualand do not punish untrustworthy behaviour as much as they should in order to establish trust. Therefore, it pays people to break contracts and cheat on others. As a result, people learn not to let others take advantage of them and are thus less trusting in social relationships. However, in other experiments and surveys described in more detail by Vollan (2009), there are a couple of findings that highlight how the village's specific history has led to a different perception of norms, rules, and regulations. For example, the results from our social capital survey showed that people in Soebatsfontein stated that they have problems with decision-making in meetings and committees more often in comparison with other villages of the Namaqualand. One interpretation of the results is that the lack of prior experience with collective farmland management makes it more difficult to manage the commons under the new co-management legislation. Not surprisingly, in another experiment conducted by Vollan (2008), it was found that people in the old commons preferred communication to solve a social dilemma, while people in Soebatsfontein under similar situations called for external regulation (i.e. a rule where players who overharvested would get sanctioned by an external agency). In contrast to the participants' expectations, we found that this rule fosters co-operation when levels of trust are low but might lead to more selfish decisions when prior trust is high. In the case of Soebatsfontein, the choice of the penalty rule highlights the greater acceptance of outside structures and their capacity to help to build a functioning community.

Governance of land management: Until 2000, the majority of the Soebatsfontein population had no direct access to the natural resources of Namaqualand. A few community members, who worked on the farms of De Beers, were allowed to hold small herds of sheep and goats. Besides that, a few households used other communal areas in the region to keep some livestock (Surplus Peoples Project 1995, 1997). In 2000, the South African government acquired 15,069 hectare of farmland from the De Beers mining company and made the land available as commonage to the people of Soebatsfontein (Falk 2008) as part of the post-apartheid land and agrarian reform programme. The formal owner of the communal farmland is the local municipality of Kamiesberg, which is obliged to use the land for the benefit of Soebatsfontein residents. In the year 2002, the Kamiesberg Municipality introduced grazing regulations on the commonage. In addition, it developed various regulations in cooperation with the community and national NGOs such as the Legal Resource Centre and Surplus Peoples Project. Examples include the Soebatsfontein Management Plan and individual contracts between farmers and the municipality.

In terms of the regulations regarding access to land, the grazing regulations give the municipality the ultimate formal power to allow and deny access to the commonage. The main selection criteria are residency in Soebatsfontein, the carrying capacity of the land, the production capacity of the farmer, the neediness of the farmer and her/his history of commonage use. The municipality is obliged to improve the access of poor, previously disadvantaged, and female members of the community to commonage resources, in particular. Farmers earning more than approximately US$ 180 per month may be excluded from using the land.

By signing a contract with the municipality, farmers agree to the rules of the commonage management plan and the grazing regulations, as well as the regular payment of grazing fees per head of livestock. The grazing contract specifies the camp to be used and the period of the contract. Farmers gain access to two camps, which they are supposed to use, together with the other camp occupiers, for rotational grazing (RSA 2002).

An elected commonage committee is installed as the advisory and executive panel, which liaises with local government but does not have the power to make, change, or abolish institutions. It is supposed to implement the commonage management plan and grazing regulations (Falk 2008).

The key problem with commonage management at Soebatsfontein is that neither the municipality nor the commonage committee effectively regulate and coordinate resource use. Sophisticated rules regarding stocking rates, water rights, payment of grazing fees, maintenance of infrastructure, and firewood collection are ignored because they are not enforced. Commonage management at Soebatsfontein is therefore a good example of an institutional challenge typical within developing countries. The constraining factors are the degree and intensity of monitoring and enforcement of rules and norms rather than the formalisation of rights (O'Riordan 2002).

The municipality, which formally monopolises key management functions does, in fact, not have the capacity to fulfil its own self-given duties. One example is the maintenance of infrastructure (RSA 2002). If fencing or water installations break down, the farmers have to inform the municipality. The municipality is either obliged to repair the damage or must agree that funds will be made available for the material used by the community to repair damages. In 2004, tensions arose when urgent maintenance measures were required, but the municipality did not even respond to requests by the farmers. As a result, more and more farmers

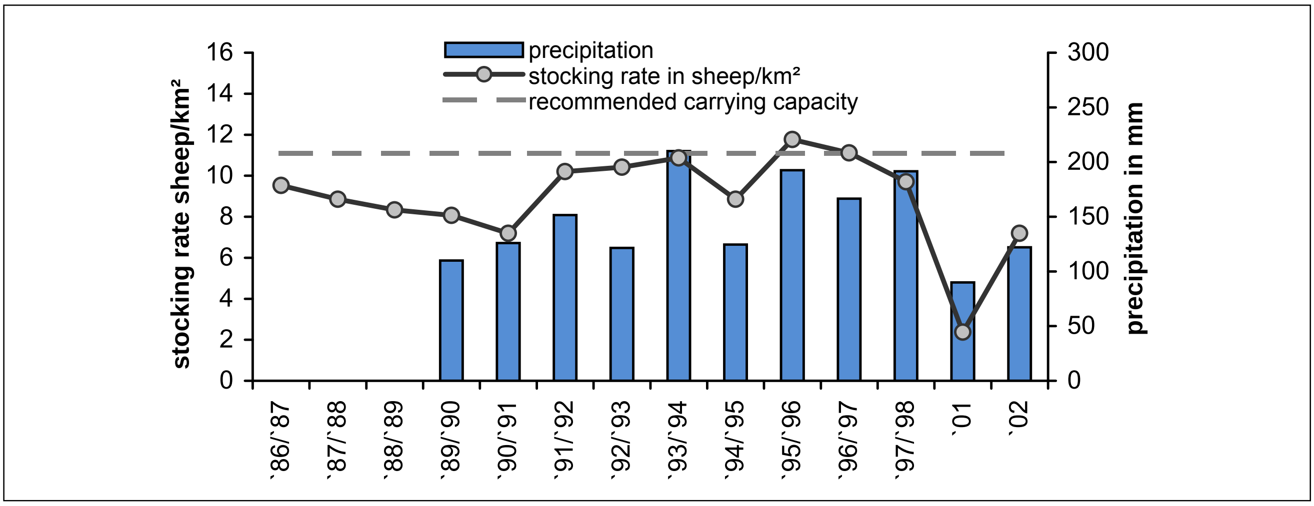

Fig. 11: The fluctuation of stocking rates (livestock use-intensity) in relation to annual precipitation on the Soebatsfontein commonage. The land was transferred to the Soebatsfontein community in 2000. The data previous to 2000 reflect the number of livestock maintained by De Beers on the area Sources: rainfall and stocking rates 1986–1998: De Beers; rainfall 2001/02: BIOTA; stocking rates 2001/02: U. Schneiderat, unpubl. data; based on Falk 2008.

stopped paying grazing fees because maintenance is supposed to be financed by such fees. In the spiral of tension, the municipality also failed to enforce the payment of these fees, which further highlighted its weakness (Falk 2008). Some farmers started to repair the infrastructure themselves. This increased their feelings of ownership of the commonage but undermined formal regulations. The farmers increasingly perceived that they owned their camps privately and were not willing to comply with any externally derived rules.

The commonage committee as an alternative management body is hardly accepted within the community and is considered to be functioning poorly. On the one hand, this is the result of the monopolisation of management authority by the municipality and the de-facto privatisation of portions of the commonage, which decreases the sense of ownership by the community. On the other hand, it can be seen as a confirmation of the afore mentioned weakness of community norms. The question remains whether the commonage committee could play a more important role in commonage management if it were given more authority and effective power to enforce its decisions.

In summary, subsidiary rules are weakly implemented in Soebatsfontein, which strongly increases the transaction costs of land management (Falk 2008). The local government shows little awareness of the power of endogenous institutions and their community-based enforcement (cf. Vollan 2009). The perceived distribution of property rights is becoming increasingly blurred, creating an institutional vacuum, which is a serious threat to sustainable natural resource management.

Infrastructure and stocking density: The Soebatsfontein commonage is currently (as of 2009) subdivided into 17 fenced camps ranging between 360 and 1,280 ha in size. One or two camps are allocated to each livestock owner, who typically herds his own livestock together with that of other family members. Permitted stock numbers are tied to camp size and vary between 30 SSU (Small Stock Units) and 109 SSU. According to the management plan, larger herds are supposed to be grazed in rotation, and thus should regularly be moved between the two camps allocated to the farmer. Four wind pumps provide the communal land with brackish ground water for the livestock, and the water is stored in tanks that are spread across the camps. Farmers that have direct access to a wind pump are advantaged, especially in the hot summer months, when stored water becomes scarce (Linke 2009).

Based on the experience of the agricultural extension office, the previous owner De Beers defined a recommended stocking rate of 9 ha/SSU. The records show that between 1996 and 1998 the mean stocking rate was 10.7 ha/SSU (Fig. 11), indicating that on average, the recommended stocking density was not exceeded. Nonetheless, livestock numbers decreased significantly with the transfer of the land to the Soebatsfontein community. The main reason for this is the lack of capital within the community: they were not able to buy as many livestock as the land could carry immediately. The Soebatsfontein residents believe the reduction of use-intensity has led to specific improvements, such as the disappearance of bare soil patches, the return of specific grass species (e.g. the annual *Schmidtia kalahariensis*, Kalahari Suurgraas), and the fact that bushes grow larger and grasses grow taller. In 2002, livestock numbers had already increased notably, which was aided by the subsidised government loans made available for the purchase of livestock. At this time, approximately 1,100 SSU grazed and browsed on the commonage (Schneiderat, unpubl. data, Falk 2008) and this number did not change until 2005, when approximately 1,140 SSU grazed on the land (Linke 2009). Although the total number of animals on the commonage is still far below the recommended stocking rate, grazing pressure varies considerably from camp to camp. In 2005 stocking rates ranged between 5 and 25 ha/SU (Linke 2009).

Pastoral production and herd management: In most cases, livestock is owned

Photo 18: Farmer on horse back herding his goats, 2007. Photo: Ute Schmiedel.

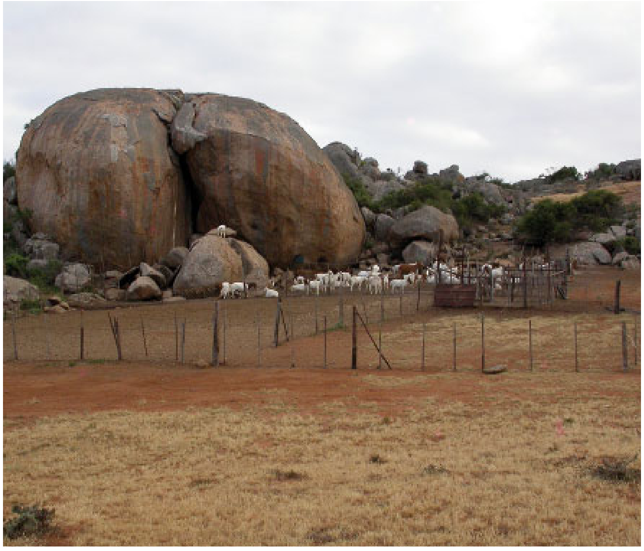

Photo 19: Stock post at Soebatsfontein commonage. Photo: Bettina Weber.

by the male head of the household and some herds include animals of several owners, who are usually close relatives (e.g. brothers). Total herd size varies from 30 to 200 animals and only larger herds contribute significantly to the cash income of households (Linke 2009). Owners usually take care of the livestock themselves (Photo 18), and in fewer cases, a herder is employed.

The small herds turned out to be more vulnerable to hazards such as epidemic diseases and predators. Beyond this, the risk of (total) animal loss depends on the herd management practices, which differ in various respects. One of the most evident differences concerns the tending of the animals: some farmers keep their herds unobserved in the camps and herd them only twice to four times a month to the kraal; other herders stay continuously at the stock post and herds are observed on a daily basis (Linke 2009). Herd size and management are to some extent dependent on farmer preferences, but available household resources are also constraining factors. Only a few of the numerous low-income households own livestock and, if they do, they manage smaller herds (up to 50 SSU) which were usually purchased on a land bank loan. Since most of them rely on insecure income sources (casual work), they depend on livestock sales to pay back their loans. Moreover, most of these herds are among those that graze unobserved, thus increasing the risk of livestock loss. Only a few of the households with insecure income sources watch over their animals regularly, and in most cases these farmers then draw on the assistance of their adult sons who are still living with them. In contrast, owners of large herds belong to economically stable households. They are less dependent on livestock sales, and can use them as an extra source of income, and are able to provide maintenance of the herd either through social or economic capital (Linke 2009).

Grazing strategies: Most of the farmers with low livestock numbers let their animals graze unobserved on one single camp, whereas farmers with large herds (> 100 SSU) have two camps available. Nevertheless, most of the farmers hardly use the available pasture but keep their herds near the stock posts. Several reasons can be considered to explain this practice, which often causes local overstocking with up to 5 ha/SSU (Linke 2009).

The construction of infrastructure facilities, such as stock posts with shelter for the herder and the lambs, is restricted to one main camp. The stock post is typically built near a wind pump or other water source, which have to be monitored above all during the hot summer months. Farmers are reluctant to move their entire herd to the additional camps, as they depend on this infrastructure, especially when lambs are born. Instead, to take advantage of the second camp, some of them subdivide their herds into different management units while keeping the newborn lambs and pregnant ewes close to the stock post (Photo 19). Splitting up the herds is suboptimal compared to rotational grazing (i.e. moving the entire herd between camps) as the latter would allow the camps to rest for some time. Nevertheless, compared to camps that do not get any rest, reducing the grazing pressure for some time seems to be the better option. However, observation has shown (Linke 2009) that, in most of the cases, the entire herd is kept close to the stock post, resulting in high grazing pressure in the main camp. Splitting the herds is not favoured by the farmers because they cannot observe the different management units at the same time and animals therefore run the risk of being caught by predators. Furthermore, splitting the herd substantially increases the amount of work. Herders have to stay near the stock post (to take care of lambs, water, etc.) and additionally watch over the animals on the second camp, which is often reached on foot.

These difficulties could be addressed by closer cooperation between the farmers, which could improve the provision and maintenance of infrastructure, transport on the farms, efficiency of herd management, and grazing strategies. However, the above mentioned tensions

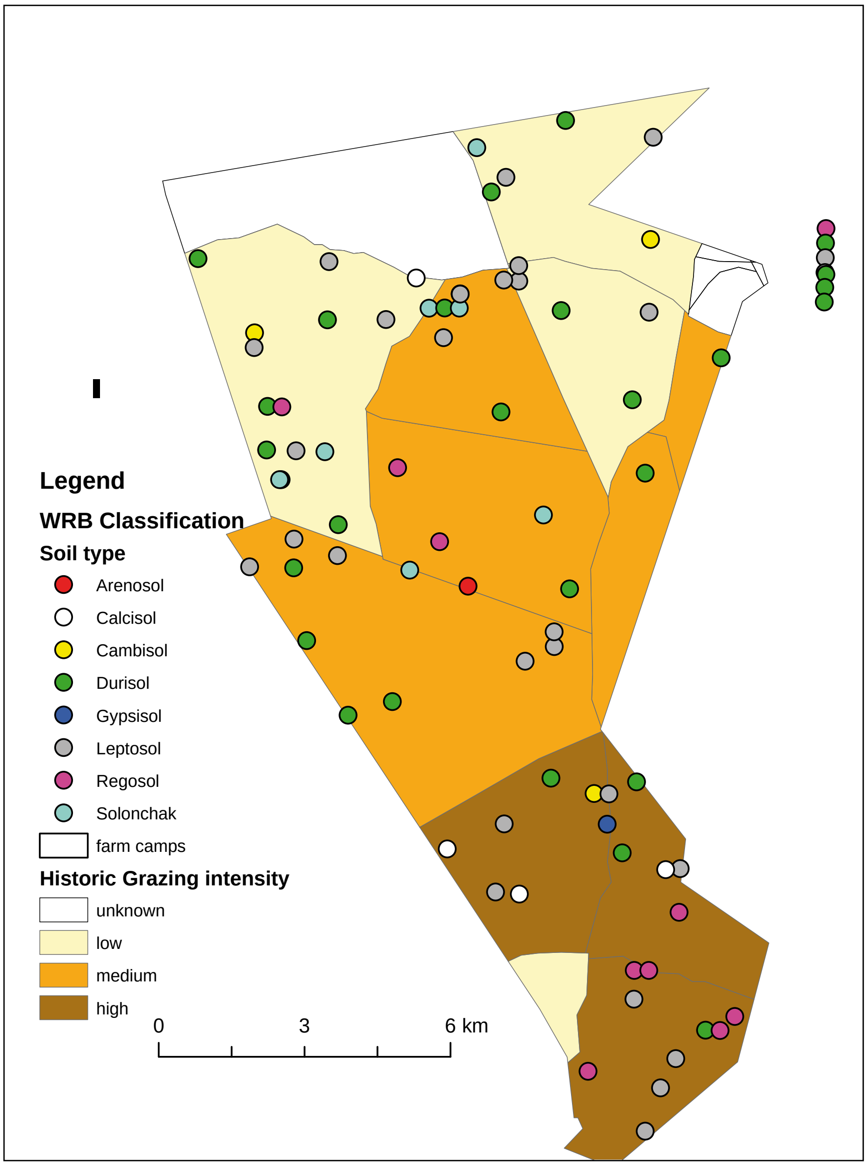

Fig. 12: Distribution of soil types on the Soebatsfontein commonage.

within the community might not favour the creation of cooperative solutions.

Effect of past and recent landuse on soil and vegetation

The Soebatsfontein commonage is characterised by an extraordinarily high diversity of soils, biological soil crusts, and vascular plants. This diversity is typical of the Succulent Karoo Biome (Mucina et al. 2006) in general, and the Namaqualand in particular (Desmet 2007). However, the potentially negative impacts of unsustainable landuse on biodiversity is undisputed (Riginos & Hoffman 2003, Mayer et al. 2006, Anderson & Hoffman 2007, Pufal et al. 2008, Todd & Hoffman 1999, 2009) and communal farmlands are frequently used as negative examples (Allsopp et al. 2007b). This second part of the chapter provides an account of the biodiversity patterns on the Soebatsfontein commonage and investigates whether these biodiversity patterns are influenced by land management. The Soebatsfontein commonage has experienced two types of land management in recent history: a) the pre-communal land management (until 1999) by the previous land owner, the De Beer Company, and b) the recent land management by the Soebatsfontein community (since 2000). The two land management types have largely been characterised by reverse patterns of use-intensity: those camps that were heavily grazed in the past are typically grazed with low intensity under the recent management in order to allow for the vegetation to recover, and vice versa. Our research attempted to detect the effects of the long-term impacts of the historic management and, the relatively short-term impacts of the recent management on the soil features and vegetation patterns on the Soebatsfontein commonage.

Soils: Soils on the Soebatsfontein commonage are characterised by high heterogeneity at different spatial scales (see Subchapter IV.4.2). Eight different soil types were identified according to the World Reference Base for Soil Resources (2006). The dominant soils are Haplic Leptosols, which are very shallow soils above continuous bedrock, and Epipetric Durisols, which are soils with a strongly cemented horizon of secondary silica (SiO_2) ('dorbank') within 50 cm from the soil surface, covering about 30% of the sampled sites (Fig. 12). The shallow soils are unfavourable habitats for perennial plants, as their water storage potential and rooting space is limited. The soils in the study area have a sandy texture except for the hardpans. The heterogeneity of the soils on the Soebatsfontein commonage is mainly due to high variance in soil pH, electrical conductivity, carbon and nitrogen contents, as well as nutrient availability (as derived from the amount of water-soluble ions). Parent material, topography, and biological activity in the form of heuweltjies (i.e. termitaria, see Subchapter IV.4.2) are the main factors responsible for this variability (Petersen 2008), with the latter especially influencing small-scale heterogeneity (Herpel 2008). Hence, the Soebatsfontein area is not only a hotspot of biodiversity but also of pedodiversity, i.e. diversity of soil types (Petersen 2008).

Comparison of the soil features within the three historic grazing classes showed a significant decrease of soil pH (Fig. 13) and plant-available phosphorous content, and an increase of C/N-ratio (i.e. the ecologically relevant ratio between carbon and nitrogen), nitrogen and organic carbon contents (Table 6) with increasing historic grazing intensity (Labitzky 2009). However, due to the generally high heterogeneity of soils in the area, it is extremely difficult to separate landuse from other factors that may have an influence on soil properties. Since general landuse effects on all soil types cannot be proved, we compared only those soil types occurring in sufficient amounts in all grazing classes (i.e. Leptosols and Durisols). We found a significant correlation between plant-available phosphorous and historic landuse intensity for all soil types. For C/N ratio, significant differences between landuse classes were restricted to Durisols and for soil pH to Leptosols, respectively (Labitzky 2009).

However, the relationship between nutrient enrichment or soil pH and historic grazing intensity as indicated by our analysis above is unlikely to be causal as they contradict the findings from other studies. In contrast to our findings, most other studies showed that degraded soils along grazing gradients tend to be more alkaline (Allsopp 1999a, Carrick 2003, Mills & Fey 2003, Gebremeskel & Pieterse 2007) due to a loss of vegetation cover, which in turn reduces the amounts of basic cations absorbed and acids secreted by plants (Mills & Fey 2003). Hence, we assumed that other factors may be responsible for these trends and therefore also compared our soil data with recent grazing intensities, which are partly a reversal of historic grazing trends (see above). The results of this analysis were more in line with previous studies, with pH increasing and C/N-ratio decreasing significantly from low to intermediate grazing intensities (the differences due to high grazing intensity was not significant due to the small sample size).

Although there is a statistically significant relationship evident, this does not necessarily indicate a causal relationship. The soil heterogeneity is extremely high and soil and historic landuse are not randomly spread across the commonage but follow a north-south gradient (Fig. 10), which seems to be related to a gradient of increasing fog and rainfall precipitation towards the south (B. Weber, unpubl. data). Hence, the observed trend in soil pH may be driven either by rainfall or grazing pressure or by both.

Vascular plants: The vegetation patterns of vascular plants on the Soebatsfontein

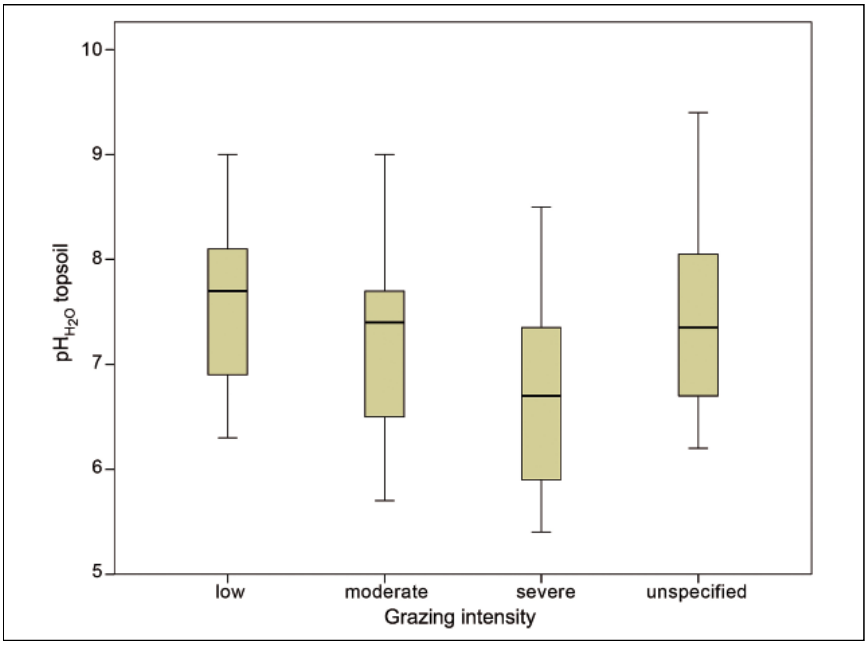

Fig. 13: Topsoil pH under different historical grazing intensities: low (*N* = 26), moderate (*N* = 25), severe (*N* = 24), and unspecified (*N* = 16).

Table 6: Correlation of topsoil properties to historic grazing intensity

Parameter	Median for low grazing intensity (*N* = 26)	Median for high grazing intensity (*N* = 24)	Significance of t-test
pH_{H2O}	7.7	6.7	0.001
$C_{organic}$ (%)	0.64	0.84	0.009
N_{total} (%)	0.065	0.076	0.018
C/N-ratio	10.3	11.2	0.024
P_{pv} (g/kg)	0.042	0.013	0.013

independent two-way t-test, pv = plant available

Photo 20: Soebatsfontein commonage after good seasonal rainfall in August 2006. Photo: Ute Schmiedel.

Table 7: Grazing response of heuweltjie centres (multiple linear regressions)

	Standardised coefficient	SEM	Estimate	SEM	Tolerance	*t*	*p*
pH, Adjusted R^2 = 0.084, F (1,21) = 3.006, p = 0.098							
Intercept			8.317	±0.153		54.232	**< 0.001**
Relative historic grazing intensity	–0.354	±0.204	–0.003	±0.002	1.000	–1.734	0.098
$CaCO_3$ (4th root), Adjusted R^2 = 0.034, F (1,21) = 1.763, p = 0.199							
Intercept			1.387	±0.191		7.257	**< 0.001**
Relative historic grazing intensity	–0.278	±0.210	–0.003	±0.002	1.000	–1.328	0.199
Vegetation cover (log_{10}), Adjusted R^2 = 0.427, F (2,20) = 9.181, p = 0.001							
Intercept			1.330	±0.113		11.725	**< 0.001**
Relative recent grazing intensity	–0.578	±0.174	–0.027	±0.008	0.864	–3.328	**0.003**
Relative historic grazing intensity	0.223	±0.174	0.001	±0.001	0.864	1.281	0.215
Cumulative palatability, Adjusted R^2 = 0.022, F (1,21) = 1.505, p = 0.233							
Intercept			13.500	±6.703		2.014	0.057
Relative historic grazing intensity	0.259	±0.211	0.082	±0.067	1.000	1.227	0.233
Species richness, Adjusted R^2 = 0.137, F (2,20) = 2.740, p = 0.089							
Intercept			13.323	±5.046		2.640	**0.016**
Relative historic grazing intensity	0.322	±0.213	0.054	±0.036	0.864	1.510	0.147
Relative recent grazing intensity	–0.236	±0.213	–0.406	±0.367	0.864	–1.105	0.282
Shannon index, Adjusted R^2 = 0.027, F (1,21) = 1.615, p = 0.218							
Intercept			1.030	±0.273		3.767	**0.001**
Relative historic grazing intensity	0.267	±0.210	0.003	±0.003	1.000	1.271	0.218
Cover annuals (log_{10}), Adjusted R^2 = 0.007, F (1,21) = 1.162, p = 0.293							
Intercept			0.135	±0.157		0.860	0.400
Northing	0.229	±0.212	0.260	±0.242	1.000	1.078	0.293
Chamaephyte cover, Adjusted R^2 = 0.302, F (2,20) = 5.768, p = 0.011							
Intercept			15.256	±7.160		2.131	**0.046**
Relative recent grazing intensity	–0.421	±0.192	–1.147	±0.521	0.864	–2.200	**0.040**
Relative historic grazing intensity	0.305	±0.192	0.081	±0.051	0.864	1.594	0.127
Bioturbation (4th root), Adjusted R^2 = 0.070, F (1,21) = 2.652, p = 0.118							
Intercept			2.061	±0.468		4.402	**< 0.001**
Relative historic grazing intensity	–0.335	±0.206	–0.008	±0.005	1.000	–1.628	0.118

N = 23
Model selection via forward selection, significant partial estimates with bold *p*, *F*-to-enter = 1.0
Full models include predictor variables recent and historic grazing intensity, northing.

commonage (Photo 20) are strongly driven by the aforementioned soil heterogeneity. In total, 17 different plant communities have been identified on the commonage, with the main driving factors being soil water availability, salinity and soil pH (Luther-Mosebach 2009, see Subchapter IV.4.2).

These strong abiotic drivers of vegetation patterns seem to mask the historic grazing effects on the scale of the present vegetation units in Soebatsfontein (Luther-Mosebach 2009). To distinguish the effect of historic or recent grazing intensity from the effects of the above-mentioned latitudinal gradient in soil features on the vegetation, we restricted our analysis to vegetation and soil variables of plots at the centre of heuweltjies. Heuweltjie centres are clearly distinct from their surroundings in terms of soil and vegetation features (Röwer 2009) and are preferred grazing areas due to the presence of higher concentrations of ions (Armstrong & Siegfried 1990) and can thus be employed as sensitive indicators of grazing impacts. We used historic and recent grazing classes as well as orientation towards north (northing) as a substitute for exposition to the four main points of the compass as predictor variables for the model (Table 7). The analyses showed no correlation of any of the predictor variables with any of the soil variables. The only significant correlation was the negative correlation of recent grazing intensity with total vegetation and chamaephyte (i.e. shrub) cover. Historic grazing intensity did not show any significant results. The fact that we did not find any response of the soil variables with grazing intensity supports our earlier finding that soil variables on heuweltjies are rather unique (Röwer 2009, Subchapter IV.4.2). They also did not seem to be affected by the climatic north-south gradient on the Soebatsfontein commonage. It can thus be assumed that the observed response of the total vegetation and chamaephytes cover to recent grazing intensity is not caused by collinearity with any of these factors. A decrease in chamaephyte (shrub) cover in favour of annual plant cover has been described as a characteristic response of Namaqualand vegetation to high grazing pressure (Todd & Hoffman 1999, 2009, Anderson & Hoffman 2007). The cover of annual plants on sites with high grazing pressure varies with the timing and total amount of seasonal rainfall (Todd & Hoffman 1999), which could also explain the absence of any significant response to recent grazing intensity.

Based on the analysis of the exclosure camps at Quaggafontein and Patrysegat, we found a measurable effect of recent grazing on the vegetation (Meyer 2009). In the camp with intensive recent grazing (Quaggafontein), the vegetation of the control plots (plots without active restoration measures) inside the exclosure showed a more significant increase in the cover of annual plant species (mean = 7.48%) than grazed plots outside (mean = 3.88%). Also, total species richness increased by 25% inside the exclosure. Under moderate recent grazing at Patrysegat, the annual vegetation cover of the control plots was unaffected by the resting inside

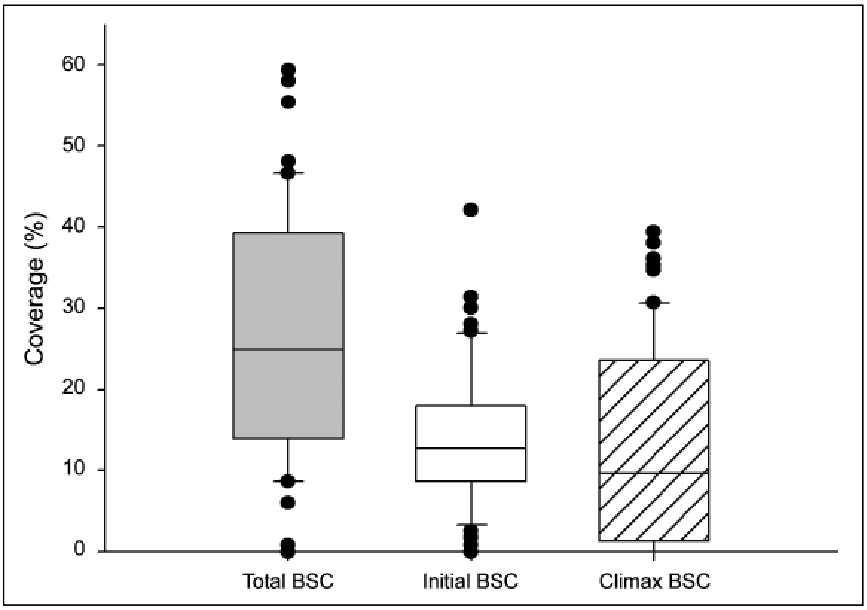

Fig. 14: Cover of the different types of biological soil crusts (BSC; *N* = 60) on the Soebatsfontein commonage.

Table 8: Response of biological soil crusts (BSC) to two grazing related parameters

	Local utilisation (number of faecal pellets/0.375 m²)		Distance to stock post or watering point (m)	
	r	*p*	*r*	*p*
Total BSC cover (%)	–0.340	0.0079	0.257	0.0475
Initial BSC cover (%)	–0.099	0.4510	0.024	0.8575
Climax BSC cover (%)	–0.340	0.0079	0.275	0.0337

Spearman rank test, *N* = 60

the exclosure, but the cover and species richness of perennials inside the exclosure decreased by 25% and 27%, respectively (see also Subchapter IV.4.4). The results indicate that increasing current grazing pressure is having a negative impact on the vegetation cover. Grazing exclosures facilitated an increase of annual plant cover. Moderate grazing, however, allowed an increase in perennial vegetation with the annual plant cover remaining the same inside and outside the exclosure.

Biological soil crusts: Our study of the soil and biological soil crusts (BSC) showed measurable effects of current landuse. The soils of Soebatsfontein are not only extraordinary diverse, but their surfaces also contain an extraordinarily high cover and diversity of biological soil crusts (Büdel et al. 2009).

Total cover of biological soil crust on the Soebatsfontein commonage was highly variable (0–60%, median 25%; Fig. 14), which complies with our remote sensing assessments (see Article III.4.1) as well as with findings from the Kalahari (Dougill & Thomas 2004, Thomas & Dougill 2006). Coverage of initial and well developed (climax) BSC in the study area was similar (median 12.7% and 9.7%, respectively; Fig. 14) but that of climax BSC varied more strongly. However, both the amount and composition of BSC depended on current landuse patterns. The total coverage of biological soil crusts was found to be negatively correlated with local utilisation intensity (according to density of livestock faecal pellets) and positively correlated with the distance to the next stock post or watering point (Table 8). The response of BSC to landuse intensity depended on their successional stage: whereas the cover of well-developed climax BSC and total

BSC responded very similarly, the coverage of initial BSC showed no response to grazing (Table 8). The results suggest a strong influence of grazing both on the absolute coverage and the composition of BSC. The high sensitivity of BSC towards disturbances, e.g. grazing, is well-described in the literature (Belnap 1995, Belnap & Gillette 1998, Warren & Eldridge 2003) and especially well-developed BSC (climax BSC) are known to be susceptible to grazing because they are easily destroyed and grow slowly (Belnap 2002a, Thomas & Dougill 2006). Initial biological soil crusts, on the other hand, can recolonise open soil within eight months or one rainfall season and are therefore less affected by landuse impacts (Dojani et al., submitted). In areas with low grazing and trampling intensities, climax BSC start to replace initial BSC within 20 months, whereas in areas with high livestock utilisation intensities, constant disturbance probably prevents succession (Dojani et al., submitted).

Consequences for land management in Soebatsfontein

The Soebatsfontein commonage is an extraordinarily (bio-) diverse farmland, a fact that is also appreciated by most of the members of the Soebatsfontein community who are the current custodians of the land. Our study indicates that heterogeneity in geomorphology, soil water availability, bioturbation (heuweltjies), and soil characteristics are probably the main drivers of this high biological diversity. The soil and therefore vegetation patterns are not evenly distributed across the commonage but largely follow a north-south gradient, which may also be related to the frequency and amount of rainfall and fog from the coast. The high heterogeneity of abiotic factors, varying durations of historic and recent landuse intensities, and the lack of benchmark sites without any grazing history, make the analysis of the impacts of anthropogenic factors difficult. Therefore, our data on soils and vascular plants on the Soebatsfontein commonage does not show unambiguous signs of an overall impact by either historical or current landuse patterns.

However, grazing and trampling by livestock is typically patchy and does not occur homogenously within each camp. Our studies on disturbance-sensitive ecosystem components such as biological soil crusts and vegetation at the centre of heuweltjie, as well as the comparison of fence-line contrasts (inside and outside of exclosures), revealed local effects of current grazing practices on the Soebatsfontein ecosystem.

With regard to biological soil crusts, both their abundance and composition was found to be strongly correlated with recent local landuse intensity. Since biological soil crusts play a major role in semi-arid and arid ecosystems by effectively reducing soil erosion and promoting the growth and nutrient status of vascular plants (Belnap & Eldridge 2003, Belnap et al. 2003c), their large-scale existence has to be ensured. Only if landuse intensity is kept within a moderate range are biological soil crusts able to provide their invaluable ecosystem services that promote sustainable land management.

However, it is likely that landuse pressure on the Soebatsfontein commonage will increase in the future. The main reason for this is the closure of the surrounding mines, with the result that former mine workers have the financial means and economic vision to become fulltime farmers for their livelihood (Anseeuw & Laurent 2007)—a general trend that also applies to the Soebatsfontein community (U. Schmiedel, own observations). Concerted efforts towards sustainable land management will therefore become increasingly important.

Our data and observations allow us to suggest some landuse management measures that should benefit both landusers and biodiversity by improving utilisation of the existing resources without requiring additional land and financial resources.

1. The available grazing resources could be used more efficiently if the grazing and resting periods per camp were guaranteed through proper rotational grazing and the sharing of manpower for herding. This may require temporary sharing of camps in order to allow other camps to rest.
2. The gathering of animals overnight at the stock post ("kraaling") requires much movement of the animals and therefore causes additional trampling and unequal utilisation of the camp. Many farmers see "kraaling" as critical to protect their livestock against predators (mainly jackals and caracal). However, alternative strategies such as the introduction of Andalusian sheepdogs as guards for the livestock (currently tested by South African National Parks) or other strategies recommended by The Cape Leopard Trust (Quinton Martins, personal communication) should be explored.
3. More efficient use of the available camps could also be attained through the installation of more, or strategically better distributed, water points within the camps. A denser network of water points could potentially reduce the local impacts experienced around the current water points. Such measure could be further enhanced if only small amounts of water were supplied at each water point, as is applied by farmers in Australia (B. Büdel, pers. comm.). This would support the movement of herds within the camps.
4. The condition of fences also needs to be improved in order to keep livestock in the delineated camps. Future land management strategies should be accompanied by a simple but effective monitoring programme, which combines landuser experiences and criteria (Desert Research Foundation of Namibia 2005) with quantitative, scientifically sound methods. The monitoring activities should assess the effects of management on the natural resources and livestock condition, allowing for the evaluation of management impacts against management objectives.

The mentioned recommendations towards more efficient use of the natural resources seem to be straight forward. However, they need to be considered within the local context. Any intervention interacts with local settings, which have been shaped by the complex interrelationship between historical, social, and economic factors, and have to be adapted to the community context. For example, cooperative management to improve grazing and herding strategies is a difficult task to undertake. This is particularly true at Soebatsfontein, where farmers and community members cannot build on past experience of joint management, as the farmland was only transferred to the community in 2000. This may also be one of the reasons why socio-economic analysis revealed that social tensions are apparent and trust is comparatively low within this community. Furthermore, the management of the commonage is constrained by economic problems, as the unemployment rate is high, employment opportunities are restricted, and the farmland is too small to serve as an additional source of income for the entire community.

Therefore, the formulation of an approach to improve land management on the Soebatsfontein commonage should be developed following a participatory process and should be based on several steps, which are outlined in the overall conclusion.

4.6 Conclusions and further research needs

[U. Schmiedel & T. Linke]

The Succulent Karoo Biome in general and Namaqualand (i.e. the western part of the Succulent Karoo Biome) in particular, has been widely acknowledged for its high biodiversity (Myers et al. 2000). The BIOTA Observatories in the Succulent Karoo harbour the highest density of vascular plant species per surface area at various spatial scales along the arid part of the BIOTA transects (Article III.3.8). The plant species richness of the Succulent Karoo is only exceeded by the Fynbos Biome, which receives much higher annual rainfall. The high biodiversity of the Succulent Karoo has been related to various factors (for overview on recently discussed drivers of biodiversity in the Succulent Karoo see also Mucina et al. 2006) related to current and historic climatic features (Desmet & Cowling 1999) but also the habitat and soil diversity of the area has been identified as an important driver (Jürgens 1986, Schmiedel & Jürgens 1999, Herpel 2008, Petersen 2009, Petersen et al. 2010, Articles III.3.3, III.3.8, Subchapter IV.4.2).

Low annual rainfall (app. 50–250 mm a^{-1}, Desmet 2007, see Part II.2) and the dominance of slow-growing dwarf shrubs, results in a comparatively low primary production (Article III.3.10), which results in a low recommended carrying capacity (10 ha/SSU, Baker & Hoffman 2006) and relatively low agricultural potential of the area (Desmet 2007). This is particularly problematic for communal farmers that have restricted financial and natural resources. The lack of alternative livelihood options (Anseeuw & Laurent 2007, Subchapter IV.3.5) and lack of appropriate technical skills and training make agriculture an important source of income for a significant number of people living in the communal areas.

However, the biodiversity contained within the over-crowded, heavily-grazed communal areas has often been transformed in terms of both its species and life form composition (Todd & Hoffman 1999, 2009, Anderson & Hoffman 2007, Rutherford & Powrie 2010) with knock-on effects for other animal groups (Article III.5.7) and the abiotic environment (Article III.3.3, Subchapter IV.4.3). In particular, our studies on quartz fields in the Knersvlakte showed that local and habitat endemics seem to be most strongly affected by such homogenising impacts of trampling and ripping of the soil surface (Etzold 2006, Haarmeyer et al. 2010). However, ploughing, mainly applied by commercial farmers to extensive areas may have a much more devastating and long-lasting effect (Subchapter IV.4.3) than overgrazing (Rahlao et al. 2008).

Our socio-economic studies from Soebatsfontein have shown that the solutions for the challenges of communal land management, which have been described in Subchapter IV.4.5, have to go beyond scientific recommendations concerning improvement in rangeland and herd management and changes in infrastructure. In the long-term, the economically- and socially-disadvantaged communities on the communal lands of Namaqualand also need perspectives that go beyond the current landuse and livelihood options. Thus the approach towards sustainable management of the communal lands in Namaqualand should follow several steps that require different timelines, structured in immediate steps and medium-term (decade) to long-term (several decades) strategies, which are outlined in the following.

The implementation of a sustainable management plan, as a **first step**, has to be adapted to the specific conditions of the respective communities. The case of Soebatsfontein showed that even if camps are allocated to single farmers, co-operative management strategies could lead to a more effective use of the available resources. However, "young" communal farming communities like Soebatsfontein received access to communal land relatively recently and cannot draw on long-standing experiences regarding joint and coordinated pasture management. Furthermore, interpersonal tensions as well as social and economical problems in the communal farming communities in Namaqualand have to be taken into account.

Most of the communities are not homogeneous entities but are rather characterised through groups and actors with different interests and capacities. Such challenges could be overcome though a strongly transdisciplinary (Max-Neef 2005) and participatory process (Wadsworth 1998, Kemmis & McTaggart 2000) as part of participatory action research. Such an approach, which can be taken as a first immediate step to improve the social and natural environment, has to be focussed around the communal farming communities but also involve various other local stakeholder groups (e.g. municipality, extension services, nature conservation authorities, rural development initiatives but also researchers and well-trained para-ecologists; see Article III.8.3). The aim of such an approach is to assess the current challenges that are experienced by the farmers and community members and to jointly explore, test, and evaluate new approaches towards an adapted and cooperative management of ecosystem services. The participatory action research process would also require the involvement of competent community workers that can help to resolve the social and economic challenges within the small communities as a precondition for fruitful cooperation. Cooperative management can improve the economic situation and strengthen empowerment of small-scale farmers as experiences from other projects in Namaqualand have shown (Nel et al. 2007, Oettlé 2005, Oettlé et al. 2009).

Participatory approaches should also facilitate access to farmland and to farming resources for economically disadvantaged households and particularly women, who currently benefit least from communal farmland (Kleinbooi & Lahiff 2007, Lebert & Rohde 2007, Subchapter IV.4.5). This aim would also be in line with the objectives of the South African land reform programme (May & Lahiff 2007).

In a **medium-term perspective**, access to more farmland is needed to make farming economically viable for a larger group of community members in Namaqualand, for whom small-livestock farming appears to be the most important, if not only, livelihood option. All those working and living in Namaqualand need to appreciate the historical legacy of apartheid in the area and the significant social, cultural, and ecological impact it has had on people's lives as well as the current spatial arrangement of communal and private farms. However, communal farmland, currently about 37% of Namaqualand area (Desmet 2007), has to be shared with other landuse options and related ecosystem services like farming on privately owned land (currently about 50% of the area in Namaqualand, Desmet 2007) and nature conservation and (eco-) tourism (only 3% of the land in 2007, Desmet 2007). The latter has become increasingly important in the Succulent Karoo Biome over the last decade, which has resulted is a perceived 'competition' for land with other landuse options like communal farming or farming by emerging farmers. This has resulted in a somewhat irrational and unfortunate dichotomy (see Benjaminsen et al. 2008) between "biodiversity conservation" on the one hand and "poverty alleviation" on the other (Roe 2008), which is also known from similar situations in other regions (Shackleton et al. 2001). Again, a participatory action research process should tackle this perceived dichotomy and explore the scope for synergies between the different landuse options (see for instance a discussion of the flower display at fallow ploughed lands as a potential tourist attraction, Subchapter IV.4.3). This is particularly critical considering the threatened economic and ecological viability of arid Namaqualand under the current climate change projections (Midgley & Thuiller 2007, Article III.2.1).

Due to climate change projection and low economic potential of agriculture in the area in general, alternative livelihood options need to be explored further for the region. Pluriactivity is a widespread and successful strategy for farmers in this relatively unpredictable natural and social environment (Anseeuw & Laurent 2007, Cousins et al. 2007). However, pluriactivity and alternative livelihoods require broadening the field of experiences and skills in the rural communities. Therefore, in a **long-term perspective**, secondary and tertiary education has to be mainstreamed and vocational training opportunities are needed in order to develop alternative livelihoods for the rural community members of Namaqualand.

Acknowledgements

The authors' general acknowledgements to the organisations and institutions, which supported this work are provided in Volume 1.

References

AG Boden (2005): Bodenkundliche Kartieranleitung. Ed. 5. – Hannover: Schweizerbart'sche Verlagsbuchhandlung.

Agriculture Research Council (undated): AGIS. Agricultural geo-referenced information system. – www.agis.agric.za [acc. 10.02.2010].

Allsopp, N. (1999a): Consequences of vegetation change associated with livestock management to soil patterns and processes in southern Africa. – In: D. Eldridge, D. Freudenberger (eds.): People and rangelands building the future. Proceedings of the VIth International Rangeland Congress **1**: 96–101. Aithkenvale: International Rangeland Congress.

Allsopp, N. (1999b): Effects of grazing and cultivation on soil patterns and processes in the Paulshoek area of Namaqualand. – Plant Ecology **142**:179–187.

Allsopp, N., Gaika, L., Knight, R., Monakisi, C., Hoffman, M.T. (2007a): The impact of heavy grazing on an ephemeral riversystem in the succulent karoo, South Africa. – Journal of Arid Environments **71**: 82–96.

Allsopp, N., Laurent, C., Debeaudoin, L.M.C., Samuels, M.I. (2007b): Environmental perceptions and practices of livestock keepers on the Namaqualand Commons challenge conventional rangeland management. – Journal of Arid Environments **70**: 740–754.

Anderson, P., Hoffman, M.T., Holmes, P.M. (2004): The potential of *Cephalophyllum inaequale* (L. Bolus) for the restoration on degraded arid landscapes in Namaqualand, South Africa. – Restoration Ecology **12**: 343–351.

Anderson, P.M.L., Hoffman, M.T. (2007): The impacts of sustained heavy grazing on plant diversity and composition in lowland and upland habitats across the Kamiesberg mountain range in the Succulent Karoo. – Journal of Arid Environments **70**: 686–700.

Anonymous (1986): Agricultural development programme: Karoo region. – Unpublished report. Pretoria: Department of Agriculture and Water Supply.

Anseeuw, W., Laurent, C. (2007): Occupational paths towards commercial agriculture: The key roles of farm pluriactivity and the commons. – Journal of Arid Environments **70**: 659–671.

Armstrong, A.J., Siegfried, W.R. (1990): Selective use of heuweltjies earth mounds by sheep. – South African Journal of Ecology **1**: 77–80.

Aronson, J., Blignaut, J.N., Milton, S.J., Le Maitre, D., Esler, K.J., Limouzin, A., Fontaine, C., Wit, M.P. de, Mugido, W., Prinsloo, P., Elst, L. van der, Lederer, N. (2010): Are socioeconomic benefits of restoration adequately quantified? A meta-analysis of recent papers (2000-2008) in restoration ecology and 12 other scientific journals. – Restoration Ecology **18**: 143–154.

Bainbridge, D.A. (2007): A guide for desert and dryland restoration. New hope for arid lands. – Washington, D.C.: Society for Ecological Restoration International.

Baker, L.E., Hoffman, M.T. (2006): Managing variability: herding strategies in communal rangelands of semiarid Namaqualand, South Africa. – Human Ecology **34**: 765–784.

Bazzaz, F.A. (2000): Plants in changing environments. Linking physiological, population and community ecology. – Cambridge: Cambridge University Press.

Belnap, J. (1995): Surface disturbances: their role in accelerating desertification. – Environmental Monitoring and Assessment **37**: 39–57.

Belnap, J. (2002a): Biological soil crusts of Arabian Sabkhat. – In: Barth, H.J., Boer, B. (eds.): Sabkha Ecosystems: 227–237. Dordrecht: Kluwer Academic Publishers.

Belnap, J. (2002b): Nitrogen fixation in biological soil crusts from southeast Utah, USA. – Biology and Fertility of Soils **35**: 128–135.

Belnap, J. (2006): The potential roles of biological soil crusts in dryland hydrologic cycles. – Hydrological Processes **20**: 3159–3178.

Belnap, J., Eldridge, D. (2003): Disturbance and recovery of biological soil crusts. – In: Belnap, J., Lange, O.L. (eds.): Biological soil crusts: structure, function and management. – Ecological Studies **150**: 363–383. Berlin: Springer.

Belnap, J., Gardner, J.S. (1993): Soil microstructure in soils of the Colorado Plateau: The role of the cyanobacterium *Microcoleus vaginatus*. – Great Basin Naturalist **53**: 40–47.

Belnap, J., Gillette, D.A. (1998): Vulnerability of desert biological soil crusts to wind erosion: The influence of crust development, soil texture, and disturbance. – Journal of Arid Environments **39**: 133–142.

Belnap, J., Rosentreter, R., Leonard, S., Kaltenecker, J.H., Williams, J., Eldridge, D. (2001): Biological soil crusts: ecology and Management. – Technical Reference 1730-2. Denver: U.S. Department of the Interior, Bureau of Land Management.

Belnap, J., Büdel, B., Lange, O.L. (2003a): Biological soil crusts: characteristics and distribution. – In: Belnap, J., Lange, O.L. (eds.): Biological soil crusts: structure, function, and management. - Ecological Studies **150**: 3–30. Berlin: Springer.

Belnap, J., Phillips, S., Duniway, M., Reynolds, R. (2003b): Soil fertility in deserts: a review on the influence of biological soil crusts and the effect of soil surface disturbance on nutrient inputs and losses. – In: Alsharhan, A.S., Wood, W.W., Goudie, A.S., Fowler, A., Abdellatif, E.M. (eds.): Desertification in the third millennium: 245–252. Lisse: Swets & Zeitlinger Publishers.

Belnap, J., Prasse, R., Harper, K.T. (2003c): Influence of biological soil crusts on soil environments and vascular plants. – In: Belnap, J., Lange, O.L. (eds.): Biological soil crusts: structure, function and management. – Ecological Studies **150**: 281–300. Berlin: Springer.
Benjaminsen, T.A., Kepe, T., Bråthen, S. (2008): Between global interests and local needs: conservation and land reform in Namaqualand, South Africa. – Africa **78**: 223–244.
Berg, J., Dickhaut, J., McCabe, K. (1995): Trust reciprocity and social history. – Games and Economic Behavior **10**: 142.
Berg, L. van den, Kellner, K. (2005): Restoring degraded patches in a semi-arid rangeland of South Africa. – Journal of Arid Environments **61**: 497–511.
Berzborn, S. (2007): The household economy of pastoralists and wage-labourers in the Richtersveld, South Africa. – Journal of Arid Environments **70**: 672–685.
Beukes, P.C., Cowling, R.M. (2003): Evaluation of restoration techniques for the Succulent Karoo, South Africa. – Restoration Ecology **11**: 308–316.
Beukes, P.C., Ellis, F. (2003): Soil and vegetation changes across a Succulent Karoo grazing gradient. – African Journal of Range and Forage Science **20**: 11–19.
Blignaut, A., Milton, S.J. (2005): Effects of multispecies clumping on survival of three succulent plant species translocated onto mine spoil in the Succulent Karoo Desert, South Africa. – Restoration Ecology **13**: 15–19.
Bonet, A. (2004): Secondary succession of semi-arid Mediterranean old-fields in south-eastern Spain: Insights for conservation and restoration of degraded lands. – Journal of Arid Environments **56**: 213–233.
Botha, S.M, Carrick, P.J., Allsopp, N. (2008): Capturing lessons from land-users to aid the development of ecological restoration guidelines for lowland Namaqualand. – Biological Conservation **141**: 885–895.
Brunner, E., Domhof, S., Langer, F. (2002): Nonparametric analysis of longitudinal data in factorial experiments. – New York: Wiley.
Büdel, B., Weber, B., Kühl, M., Pfanz, H., Sültemeyer, D., Wessels, D. (2004): Reshaping of sandstone surfaces by cryptoendolithic cyanobacteria: bioalkalization causes chemical weathering in arid landscapes. – Geobiology **2**: 261–268
Büdel, B., Darienko, T., Deutschewitz, K., Dojani, S., Friedel, T., Mohr, K.I., Salisch, M., Reisser, W., Weber, B. (2009): Southern African biological soil crusts are ubiquitous and highly diverse in drylands, being restricted by rainfall frequency. – Microbial Ecology **57**: 229–247.
Cadenasso, M., Pickett, S.T.A., Morin, P.J. (2002): Experimental test of the role of mammalian herbivores on old field succession: Community structure and seedling survival. – Journal of the Torrey Botanical Society **129**: 228–237.
Callaway, R.M., Walker, L.R. (1997): Competition and facilitation: a synthetic approach to interactions in plant communities. – Ecology **78**: 1958–1965.
Campbell, N.A., Reece, J.B. (2005): Biology. Ed. 7. – San Francisco: Pearson Education/ Benjamin Cummings.
Carrick, P. J. (2003): Competitive and facilitative relationships among three shrub species, and the role of browsing intensity and rooting depth in the Succulent Karoo, South Africa. – Journal of Vegetation Science **14**: 761–772.
Carrick, P.J., Krüger, R. (2007): Restoring degraded landscapes in lowland Namaqualand: lessons from the mining experience and from regional ecological dynamics. – Journal of Arid Environments **70**: 767–781.
Coetzee, K. (2005): Caring for natural rangelands. – Scottsville: University of KwaZulu-Natal Press.
Connell, J.H. (1978): Diversity in tropical rain forests and coral reefs – high diversity of trees and corals is maintained only in a non-equilibrium state. – Science **199**: 1302–1310.
Cousins, B., Hoffman, M.T., Allsopp, N., Rohde, R.F. (2007): A synthesis of social and biological perspectives on sustainable land use in Namaqualand. – Journal of Arid Environments **70**: 834–846.
Cowling, R.M., Pierce, S.M. (1999): Namaqualand – a succulent desert. – Cape Town: Fernwood Press.
Cowling, R.M., Hilton-Taylor, C. (1999): Plant biogeography, endemism and diversity. – In: Dean, W.R.J., Milton, S.J. (eds.): The Karoo: ecological patterns and processes: 42–85. Cambridge: Cambridge University Press.
Cowling, R.M., Esler, K.J., Rundel, P.W. (1999): Namaqualand, South Africa – an overview of a unique winter-rainfall desert ecosystem. – Plant Ecology **142**: 3–21.
Cramer, V.A., Hobbs, R.J. (eds.) (2007): Old fields. Dynamics and restoration of abandoned farmland. – Washington, D.C.: Island Press.
Cramer, V.A., Hobbs, R.J., Standish, R.J. (2007): What's new about old fields? Land abandonment and ecosystem assembly. – Trends in Ecology and Evolution **23**: 104–112.
Critchley, W., Reij, C., Willcocks, T.J. (1994): Indigenous soil and water conservation: a review of the state of knowledge and prospects for building on tradition. – Land Degradation and Rehabilitation **5**: 293–314.
Debussche, M., José, E., Lepart, J., Houssard, C., Lavorel, S. (1996): Changes in Mediterranean plant succession: old-fields revisited. – Journal of Vegetation Science **7**: 519–526.
Desert Research Foundation of Namibia (2005): Local level monitoring for enhanced decision-making. Farmer's Field Guide. – Windhoek: Ministry of Agriculture, Water and Forestry, National Agriculture Support Services Programme (NASSP) and European Commission (EDF 8).
Desmet, P.G. (2007): Namaqualand – a brief overview of the physical and floristic environment. – Journal of Arid Environments **70**: 570–587.
Desmet, P.G., Cowling, R.M. (1999): The climate of the Karoo – a functional approach. – In: Dean, W.R., Milton, S.J. (eds.): The Karoo: ecological patterns and processes: 3–16. Cambridge: Cambridge University Press.
Dojani, S., Lakatos, M., Rascher, U., Wanek, W., Lüttge, U., Büdel, B. (2007): Nitrogen input by cyanobacterial biofilms of an inselberg into a tropical rainforest in French Guiana. – Flora **202**: 521–529.
Domingo, F., Sánchez, G., Moro, M.J., Brenner, A.J., Puigdefábregas, J. (1998): Measurements and modelling of rainfall interception by three semi-arid canopies. – Agricultural and Forest Meteorology **91**: 275–292.
Dougill, A.J., Thomas, A.D. (2004): Kalahari sand soils: spatial heterogeneity, biological soil crusts and land degadation. – Land Degradation and Development **15**: 233–242.
Dregne, H.E. (1992): Degradation and rehabilitation of arid lands. – Texas: International Centre for Arid and Semiarid Land Studies.
Dunkerley, D. L. (2008): Intra-storm evaporation as a component of canopy interception loss in dryland shrubs: observations from Fowlers Gap, Australia. – Hydrological Processes **22**: 1985–1995.
Ellis, F. (2002): Contributions of termites to the formation of hardpans in soils of arid and semi-arid regions of South Africa. – Proceedings of the 17th WCSS, Paper No 572: 1–9. Bangkok: Soil and Fertilizer Society of Thailand.
Epps, G.A. van, McKell, C.M. (1983): Effect of weedy annuals on the survival and growth of transplants under arid conditions. – Journal of Range Management **36**: 366–369.
Esler, K.J. (1999): Plant reproductive ecology. – In: Dean, W.R., Milton, S.J. (eds.): The Karoo: ecological patterns and processes: 123–144. Cambridge: Cambridge University Press.
Esler, K.J., Cowling, R.M. (1995): The comparison of selected life-history characteristics of Mesembryanthema species occuring on and off Mima-like mounds (heuweltjies) in semi-arid southern Africa. – Vegetatio **116**: 41–50.
Etzold, S. (2006): Dynamics on quartz fields in the Knersvlakte/South Africa. With special references to disturbance and restoration. – Diplom thesis in biology. Hamburg: University of Hamburg.
Evans, R.D., Lange, O.L. (2001): Biological soil crusts and ecosystem nitrogen and carbon dynamics. – In: Belnap, J., Lange, O.L. (eds.): Biological soil crusts: structure, function, and management. Ecological Studies 150: 263–279. Berlin: Springer.
Falk, T. (2008): Communal farmers' natural resource use and biodiversity preservation. A new institutional economic analysis from case studies in Namibia and South Africa. – Göttingen: Cuvillier.
Francis, M.L., Fey, M.V., Prinsloo, H.P., Ellis, F., Mills, A.J., Medinski, T.V. (2007): Soils of Namaqualand: compensations for aridity. – Journal of Arid Environments **70**: 588–603.
Gabriels, N. Allsopp, N., Hoffman, T. (2003): Seedling establishment under livestock pressure in Succulent Karoo systems: an impossible scenario? – In: Allsopp, N., Palmer, A.R., Milton, S.J., Kirkman, K.P., Kerley, G.I.H., Hurt, C.R., Brown, C.J. (eds.): Proceedings of the VIIth International Rangelands Congress. 26th July – 1st August 2003, Durban, South Africa: 65–68.
Gebremeskel, K., Pieterse, P.J. (2007): Impact of grazing around a watering point on soil status of a semi-arid rangeland in Ethiopia. – African Journal of Ecology **45**: 72–79.
Germishuizen, G., Meyer, N.L. (2003): Plants of southern Africa: an annotated checklist. – Strelitzia **14**. Pretoria: South African National Botanical Institute.
Grime, J.P. (1973): Competitive exclusion in herbaceous vegetation. – Nature **242**: 344–347.
Grime, J.P. (1979): Plant strategies and vegetation processes. – Chichester: John Wiley & Sons.
Haarmeyer, D.H. (2009): Effects of domestic livestock on the vegetation of the Knersvlakte, South Africa. – Diplom thesis. Hamburg: University of Hamburg.
Haarmeyer, D.H., Schmiedel, U., Dengler, J., Bösing, B.M. (2010): How does grazing intensity affect different vegetation types in arid Succulent Karoo, South Africa? Implications for conservation management. – Biological Conservation **143**: 588–596.

Hartmann, H.E.K. (2002a): Illustrated handbook of succulent plants: Aizoaceae A-E. – Berlin: Springer.

Hartmann, H.E.K. (2002b): Illustrated handbook of succulent plants: Aizoaceae F-Z. – Berlin: Springer.

Hennekens, S.M., Schaminée, J.H.J. (2001): TURBOVEG, a comprehensive data base management system for vegetation data. – Journal of Vegetation Science **12**: 589–591.

Herpel, N. (2008): The scale-dependent variability of topsoil properties reflecting ecosystem patchiness in drylands of Southern Africa. – Hamburger Bodenkundliche Arbeiten **62**: 1–299.

Hiernaux, P., Bielders, C.L., Valentin, C., Bationo, A., Fernández-Rivera, S. (1999): Effects of livestock grazing on physical and chemical properties of sandy soils in Sahelian rangelands. – Journal of Arid Environments **41**: 231–245.

Hilton-Taylor, C. (1994): Western Cape Domain (Succulent Karoo). – In: Davis, S.D., Heywood, V.H., Hamilton, A.C. (eds.): Centres of Plant Diversity **1**: Europe Africa South West Asia and the Middle East: a guide and strategy for their conservation: 204–224. Cambridge: IUCN Publications Unit.

Hoffman M.T., Rohde R.F. (2007): From pastoralism to tourism: The historical impact of changing land use practices in Namaqualand. – Journal of Arid Environments **70**: 641–658.

Hoffman, M.T., Allsopp, N., Rohde, R.F. (2007): Sustainable land use in Namaqualand, South Africa: Key issues in an interdisciplinary debate. – Journal of Arid Environments **70**: 561–569.

Hook, P.B., Burke, I.C., Lauenroth, W.K. (1991): Heterogeneity of soil and plant N and C associated with individual plants and openings in North American shortgrass steppe. – Plant and Soil **138**: 247–256.

Jafari, M., Tavili, A., Zargham, N., Heshmati, G.A., Zare Chahouki, M.A., Shirzadian, S., Azarnivand, H., Zehtabian, G.R., Sohrabi, M. (2004): Comparing some properties of crusted and uncrusted soils in Alagol region of Iran. – Pakistan Journal of Nutrition **3**: 273–277.

James, I., Hoffman, T., Munro, A., O'Farrell, P.J., Smart, R. (2007): The economic value of flower tourism at the Namaqua National Park, South Africa. – South African Journal of Economic and Management Sciences **10**: 442–456.

Jones, C.G., Lawton, J.H., Shachak, M. (1994): Organisms as ecosystem engineers. – Oikos **69**: 373–386.

Jürgens, N. (1986): Untersuchungen zur Ökologie sukkulenter Pflanzen des südlichen Afrika. – Mitteilungen aus dem Institut für Allgemeine Botanik Hamburg **21**: 139–365.

Kaouthar, J., Chaieb, M. (2010): Changes in soil properties and vegetation followinglivestock grazing exclusion in degraded arid environments of South Tunisia. – Flora **205**: 184–189.

Kemmis, S., McTaggart, R. (2000): Participatory action research. Handbook of qualitative research. – London: Sage.

King, E.G., Stanton, M.L. (2008): Facilitative effects of *Aloe* shrubs on grass establishment, growth, and reproduction in degraded Kenyan rangelands: implications for restoration. – Restoration Ecology **16**: 464–474.

Klak, C., Reeves, G., Hedderson, T. (2004): Unmatched tempo of evolution in Southern African semi-desert ice plants. – Nature **427**: 63–65.

Kleinbooi, K., Lahiff, E. (2007): „Die man is die hoof en vat voor": Women's attitudes to land and farming in the communal areas of Namaqualand. – Journal of Arid Environments **70**: 799–817.

Knight, R.S., Rebelo, A.G., Siegfried, W.R. (1989): Plant Assemblages on Mima-like earth mounds in the Clanwillian district, South Africa. – South African Journal of Botany **55**: 465–472.

Labitzky, T. (2009): Natural features and landuse impact on soils of the Soebatsfontein region (Namaqualand, South Africa). – Diplom thesis. Hamburg: Institute of Soil Science, University of Hamburg.

Lavorel, S., Garnier, E. (2002): Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. – Functional Ecology **16**: 545–556.

Lebert, T., Rohde, R. (2007): Land reform and the new elite: exclusion of the poor from communal land in Namaqualand, South Africa. – Journal of Arid Environments **70**: 818–833.

Li, X.Y., Liu, L.Y., Gao, S.Y., Shi, P.J., Zou, X.Y., Zhang, C.L. (2005): Microcatchment water harvesting for growing Tamarix ramosissima in the semiarid loess region of China. – Forest Ecology and Management **214**: 111–117.

Linke, T. (2009): Ethnographische Rahmenbedingungen und rezente Entwicklungen der pastoralen Landnutzung in Soebatsfontein, Südafrika. – Master's thesis in Social Anthropology. Hamburg: University of Hamburg.

Loik, M.E., Breshears, D.D., Lauenroth, W.K., Belnap, J. (2004): A multi-scale perspective of water pulses in dryland ecosystems: climatology and ecohydrology of the western USA. – Oecologia **141**: 269–281.

Lovegrove, B.G. (1991): Mima-like mounds (heuweltjies) of South Africa: the topological, ecological and economic impact of burrowing animals. – Symposium of the Zoological Society of London **63**: 183–196.

Ludwig J.A., Tongway, D.J. (1996): Rehabilitation of semiarid landscapes in Australia. II. Restoring vegetation patches. – Restoration Ecology **4**: 398–406.

Luther-Mosebach, J. (2009): Hierarchical classification of the vegetation on the communal farmland of Soebatsfontein in Namaqualand, South Africa. The role of grazing history and habitat conditions. Diplom thesis in Botany. Hamburg: Biocentre Klein Flottbek and Botanical Garden, University of Hamburg.

Mauchamp, A., Janeau, J.L. (1993): Water funnelling by the crown of *Flourensia cernua*, a Chihuahuan Desert shrub. – Journal of Arid Environments. **25**: 299–306.

Max-Neef, M.A. (2005): Foundations of transdisciplinarity. – Ecological Economics **53**: 5–16.

May, H., Lahiff, E. (2007): Land reform in Namaqualand, 1994–2005: a review. – Journal of Arid Environments **70**: 782–798.

Mayer, C., Soka, G., Picker, M. D. (2006): The importance of monkey beetle (Scarabaeidae: Hopliini) pollination for Aizoaceae and Asteraceae in grazed and ungrazed areas at Paulshoek, Succulent Karroo, South Africa. – Journal of Insect conservation **10**: 323–333.

Mbagwu, J.S.C. (1992): Improving the productivity of a degraded ultisol in Nigeria using organic and inorganic amendments. Part 1: Chemical properties and maize yield. – Bioresource Technology **42**: 149–154.

Merwe, H. van der (2009): Patterns of plant diversity in the Hantam-Tanqua-Roggeveld Subregion, Succulent Karoo, South Africa. – PhD thesis. Pretoria: University of Pretoria.

Meyer, S. (2009): Analysis and evaluation of ecological restoration experiments in the Succulent Karoo (South Africa). – Diplom thesis in Geoecology. Karlsruhe: University of Karlsruhe (TH).

Midgley, G.F., Musil, C.F. (1990): Substrate effects of zoogenic soil mounds on vegetation composition in the Worcester- Robertson valley, Cape Province. – South African Journal of Botany **56**: 158–166.

Midgley, G.F., Thuiller, W. (2007): Potential vulnerability of Namaqualand plant diversity to anthropogenic climate change. – Journal of Arid Environments **70**: 615–628.

Midgley, G.F., Hannah, L., Millar, D., Rutherford, M.C., Powrie, L.W. (2002): Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. – Global Ecology and Biogeography **11**: 445–451.

Mills, A., Fey, M.V. (2003): Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. – South African Journal of Science **99**: 429–436.

Milton, S.J. (1995): Spatial and temporal patterns in the emergence and survival of seedlings in arid Karoo shrubland. – Journal of Applied Ecology **32**: 145–156.

Milton, S.J., Dean, W.R.J. (1990): Mima-like mounds in the southern and western Cape: are the origins so mysterious? – South African Journal of Science **86**: 207–208.

Mokolobate, M.S., Haynes, R.J. (2002): Comparative liming effect of four organic residues applied to an acid soil. – Biology and Fertility of Soils **35**: 79–85.

Moore, J. M., Picker, M.D. (1991): Heuweltjies (earth mounds) in the Clanwilliam District, Cape Province, South Africa: 4000 year old termite nests. – Oecologia **86**: 424–432.

Mucina, L., Jürgens, N., Le Roux, A., Rutherford, M.C., Schmiedel, U., Esler, K.J., Powrie, L.W., Desmet, P.G., Milton, S.J. (2006): Succulent Karoo Biome. – In: Mucina, L., Rutherford, M.C. (eds.): The vegetation of South Africa, Lesotho and Swaziland. Strelitzia **19**: 221–229. Pretoria: South African National Biodiversity Institute.

Myers, N. (2003): Hotspots revisited. – Bioscience **53**: 916–917.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B. da, Kent, J. (2000): Biodiversity hotspots for conservation priorities. – Nature **403**: 853–858.

Myster, R.W., Pickett, S.T.A. (1990): Initial conditions, history and successional pathways in ten contrasting old fields. – American Midland Naturalist **12**: 231–238.

Nel, E., Binns, T., Bek, D. (2007): 'Alternative foods' and community-based development: Rooibos tea production in South Africa's West Coast Mountains. – Applied Geography **27**: 112–129.

Nobel, P.S. (1984): Extreme temperatures and thermal tolerances for seedlings of desert succulents. – Oecologia **62**: 310–317.

O'Riordan, T. (2002): Protecting beyond the protected. – In: O'Riordan, T., Stoll-Kleemann, S. (eds.): Biodiversity, sustainability and human communities: 3–29. Cambridge: Cambridge University Press.

Oettlé, N.M. (ed.) (2005): Enhancing sustainable livelihoods in the Suid Bokkeveld. – Amsterdam: Both Ends.

Oettlé, N., Goldberg, K., Koelle, B. (2009): The Heiveld Co-operative - a vehicle for sustainable local development. – Cape Town: Drynet Case Study. http://www.heiveld.co.za/resources/Heiveld-Case-Study.pdf.

Otto, R., Krüsi, B.O., Burga, C.A., Fernández-Palacios, J.M. (2006): Old-field succession along a precipitation gradient in the semi-arid coastal region of Tenerife. – Journal of Arid Environments **65**: 156–178.

Padilla, F.M., Pugnaire, F.I. (2006): The role of nurse plants in the restoration of degraded environments. – Frontiers in Ecology and the Environment **4**: 196–202.

Petersen, A. (2008): Pedodiversity of southern African drylands. – Hamburger Bodenkundliche Arbeiten **61**: 1–374

Petersen, A., Young, E.M., Hoffman, M.T., Musil, C.F. (2004): The impact of livestock grazing on landscape biophysical attributes in privately and communally managed rangelands in Namaqualand. – South African Journal of Botany **70**: 777–783.

Petersen, A., Gröngröft, A., Miehlich, G. (2010): Methods to quantify the pedodiversity of 1 km² areas — results from southern African drylands. – Geoderma **155**: 140–146.

Picker, M.D., Hoffman, M.T., Leverton, B. (2007): Density of *Microhodotermes viator* (Hodotermitidae) mounds in southern Africa in relation to rainfall and vegetative productivity gradients. – Journal of Zoology **271**: 37–44.

Pickett, S.T.A., Cadenasso, M.L., Meiners, S.J. (2008): Ever since Clements: from succession to vegetation dynamics and understanding to intervention. – Applied Vegetation Science **12**: 9–21.

Pineiro, G., Paruelo, J.M., Jobbagy, E.G., Jackson, R.B., Oesterheld, M. (2009): Grazing effects on belowground C and N stocks along a network of cattle exclosures in temperate and subtropical grasslands of South America. – Global Biogeochemical Cycles **23**: GB2003. DOI: 10.1029/2007GB003168.

Podani, J. (2001): SYN-TAX (2000): Computer programs for data analysis in ecology and systematics. – Budapest: Scientia Publishing.

Pufal, G., Mayer, C., Porembski, S., Jürgens, N. (2008): Factors affecting fruit set in Aizoaceae species of the Succulent Karoo. – Basic and Applied Ecology **9**: 401–409.

Querejeta, J.I., Roldán, A., Albaladejo, J., Castillo, V. (2000): Soil physical properties and moisture content affected by site preparation in the afforestation of a semiarid rangeland. – Soil Science Society of America Journal **64**: 2087–2096.

Rahlao, S.J., Hoffman, M.T, Todd, S.W., McGrath, K. (2008): Long-term vegetation change in the Succulent Karoo, South Africa following 67 years of rest from grazing. – Journal of Arid Environments **72**: 808–819.

Raper, P.E., Boucher, M. (eds.) (1988): Robert Jacob Gordon. Cape travels, 1777-1786. – Houghton: Brenthurst Press.

Richardson, F.D., Hahn, B.D., Hoffman, M.T. (2007): Modelling the productivity and sustainability of pastoral systems in the communal areas of Namaqualand. – Journal of Arid Environments **70**: 707–717.

Riginos, C., Hoffman, M.T. (2003): Changes in population biology of two succulent shrubs along a grazing gradient. – Journal of Applied Ecology **40**: 615–625.

Roe, D. (2008): The origins and evolution of the conservation-poverty debate: a review of key literature, events and policy processes. – Oryx **42**: 491-503.

Rohde, R.F., Hoffman, M.T. (2008): One hundred years of separation: the historical ecology of a South African 'Coloured Reserve'. – Africa **78**: 189–222.

Rohde, R., Hoffman, M.T., Allsopp, N. (2003): Hanging on a wire: A historical and socio-economic study of Paulshoek village in the communal area of Leliefontein, Namaqualand. – Research Report No. 17. Cape Town: Programme for Land and Agrarian Studies, School of Government, University of the Western Cape.

Rooyen, M.W. van (1999): Functional aspects of short-lived plants. – In: Dean, W.R., Milton, S.J. (eds): The Karoo: ecological patterns and processes: 107–122. Cambridge: Cambridge University Press.

Rooyen, M.W. van (2002): Management of the old field vegetation in the Namaqua National Park, South Africa: conflicting demands of conservation and tourism. – Geographical Journal **168**: 211–223.

Röwer, I.U. (2009): Small-scale vegetation and biodiversity patterns of termitaria (heuweltjies) under different grazing pressures in the communal area of Soebatsfontein, South Africa. – Diplom thesis. Hamburg: University of Hamburg.

RSA (2002): Government of South Africa; Kamiesberg Munisipaliteit: Weidingsregulasies. – Provincial Gazette of the Province of the Northern Cape No. 676, 04/2002.

Rutherford, M.C., Powrie, L.W. (2010): Severely degraded rangeland: Implications for plant diversity from a case study in Succulent Karoo, South Africa. – Journal of Arid Environments **74**: 692–701.

Samuels, M.I., Allsopp, N., Hoffman, M.T. (2008): Mobility patterns of livestock keepers in semi-arid communal rangelands of Namaqualand, South Africa. – Nomadic Peoples **12**(1): 123-148.

Schmiedel, U. (2002): The quartz fields of southern Africa. Flora, phytogeography, vegetation, and habitat ecology. – PhD thesis. Cologne: University of Cologne.

Schmiedel, U. (2004): The phytogeography of the obligate quartz field flora of southern Africa. – Schumannia **4**: 181–205.

Schmiedel, U., Jürgens, N. (1999): Community structure on unusual habitat island: quartz-fields in the Succulent Karoo, South Africa. – Plant Ecology **142**: 57–69.

Schmiedel, U., Jürgens, N. (2004): Habitat ecology of southern African quartz fields: studies on the thermal properties near the ground. – Plant Ecology **170**:153–166.

Schmiedel, U., Mucina, L. (2006): Vegetation of quartz fields in the Little Karoo, Tanqua Karoo and eastern Overberg (Western Cape Province, South Africa). – Phytocoenologia **36**: 1–44.

Schnegg, M. (2009): It's the combination that counts: diversification of pastoral livelihoods in northwestern Namibia. – In: Clemes, C., Kokot, W. (eds.): Networks, resources and economic action. Ethnographic case studies in honor of Hartmut Lang: 229–248. Berlin: Reimer.

Shackleton, B., Shackleton, S., Cousin, B. (2001): The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. – Development Southern Africa **18**: 581–604.

Simons, L., Allsopp, N. (2007): Rehabilitation of rangelands in Paulshoek, Namaqualand: understanding vegetation change using biophysical manipulations. – Journal of Arid Environments **70**: 755–766.

Stock, W.D., Dlamini, T.S., Cowling, R.M. (1999): Plant induced fertile islands as possible indicators of desertification in a succulent desert ecosystem in northern Namaqualand, South Africa. – Plant Ecology **142**: 161–167.

Surplus Peoples Project (1995): Survey of Soebatsfontein Community. – Unpublished Report. Soebatsfontein: Surplus Peoples Project.

Surplus Peoples Project (1997): Namaqualand district planning and management project: report on the current situation concerning livestock farming in reservations, municipal areas and areas with communal grazing in Namaqualand. – Springbok: Surplus Peoples Project.

Thomas, A.D., Dougill, A.J. (2006): Distribution and characteristics of cyanobacterial soil crusts in the Molopo Basin, South Africa. – Journal of Arid Environments **64**: 270-283.

Thurow, T.L. (2000): Hydrologic effects on rangeland degradation and restoration processes. – In: Arnalds, O., Archer, S. (eds.): Rangeland desertification: 53–66. Dordrecht: Kluwer Academic Publishers.

Todd, S.W. (2000): Patterns of seed production and shrub association in two palatable Karoo shrub species under contrasting land use intensities. – African Journal of Range and Forage Science **17**: 22–26.

Todd, S.W., Hoffman, M.T. (1999): A fence-line contrast reveals effects of heavy grazing on plant species diversity and community composition in Namaqualand, South Africa. – Plant Ecology **142**: 169–178.

Todd, S.W., Hoffman, M.T. (2009): A fence line in time demonstrates grazing-induced vegetation shifts and dynamics in the semiarid Succulent Karoo. – Ecological Applications **19**: 1897–1908.

Tongway, D.J., Ludwig J.A. (1996): Rehabilitation of semiarid landscapes in Australia. I. Restoring productive soil patches. – Restoration Ecology **4**: 388–397.

Turner, J.S. (2003): Trace fossils and extended organisms: a physiological perspective. – Palaeogeography, Palaeoclimatology, Palaeoecology **192**: 15–31.

Valentyn, F. (1971): Description of the Cape of Good Hope with the matters concerning it. – Van Riebeeck Society Pulications, 2nd ser., No. 4. Cape Town: Van Riebeeck Society.

Vetter, S. (2005): Rangelands at equilibrium and non-equilibrium: recent developments in the debate. – Journal of Arid Environments **62**: 321-341.

Villiers, A.J. de, Rooyen, M.W. van, Theron, G.K. (1992): Studies of the revegetation of saline mined soil at Namaqua sands. – Report for Anglo American Corporation. Pretoria: University of Pretoria.

Villiers, A.J. de, Rooyen, M.W. van, Theron, G.K. (2003): Similarity between the soil seed bank and the standing vegetation in the Strandveld Succulent Karoo, South Africa. – Land Degradation & Development **14**: 527–540.

Vollan, B. (2008): Socio-ecological explanations for crowding-out effects from economic field experiments in southern Africa. – Ecological Economics **67**: 560–573.

Vollan, B. (2009): Co-operation for common pool resources: an experimental perspective. – München: Dr. Hut.
Wadsworth, Y. (1998): What is participatory action research? – Action Research International, Paper 2. http://www.scu.edu.au/schools/gcm/ar/ari/p-ywadsworth98.html [acc. 17.05.2010].
Ward, D. (2009): The biology of deserts. – Oxford: Oxford University Press.
Warren, S. D. (2001): Synopsis: influence of biological soil crusts on arid land hydrology and soil stability. – In: Belnap, J., Lange, O.L. (eds.): Biological soil crusts: structure, function, and management. Ecological Studies **150**: 349–360. Berlin & Heidelberg: Springer.
Warren, S.D., Eldridge, D.J. (2003): Biological soil crusts and livestock in arid ecosystems: Are they compatible? – In: Belnap, J., Lange, O.L. (eds.): Biological soil crusts: structure, function, and management. Ecological Studies **150**: 401–415. Berlin & Heidelberg: Springer.
Watkeys, M.K. (1999): Soils of the arid southwestern zone of Africa. – In: Dean, W.R.J., Milton, S.J. (eds.): The Karoo: ecological patterns and processes: 17–25. Cambridge: Cambridge University Press.
Webley, L. (2007): Archaeological evidence for pastoralist land-use and settlement in Namaqualand over the last 2000 years. – Journal of Arid Environments **70**: 629–640.
Werger, M.J.A. (1974): On concepts and techniques applied in the Zürich-Montpellier method of vegetation survey. – Bothalia **11**: 309–323.
Whalen, J.K., Chang, C., Clayton, W.C., Carefoot, P. (2000): Cattle manure amendments can increase the pH of acid soils. – Soil Science Society of America Journal **64**: 962–966.
Witbooi, B., Esler, K.J. (2003): Old field restoration: an assessment of the influence of restoration techniques on the establishment of selected Succulent Karoo species. – Elsenburg Journal 2004: 3–7. http://www.elsenburg.com/agriprobe/2004/ej2004-1.pdf
Wong, M.T.F., Nortcliff, S., Swift, R.S. (1999): Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, farmyard manure, and peat applied to tropical soils. – Communications in Soil Science and Plant Analysis **29**: 2927–2937.
World Reference Base for Soil Resources (2006): A framework for international classification, correlation and communication. – World Soil Resources Report No. 103. Rome: Food and Agriculture Organization of the United Nations.
Yayneshet, T., Eik, L.O., Moe, S.R. (2009): The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia. – Journal of Arid Environments **73**: 542–549.
Zhang, Y.M., Wang, H.L., Wang, X.Q., Yang, W.K., Zhang, D.Y. (2006): The microstructure of microbiotic crust and its influence on wind erosion for a sandy soil surface in the Gurbantunggut Desert of Northwestern China. – Geoderma **132**: 441–449.
Zink, A.T., Allen, M.F. (1998): The effects of organic amendments on the restoration of a disturbed coastal sage scrub habitat. – Restoration Ecology **6**: 52–58.