Biodiversity in Southern Africa

Vol. 3

Implications for Landuse and Management

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BIOTA transect and the Biodiversity Observatories in southern Africa.

Uwe Ulrich Jäschke & Karen Langner • HTW - University of Applied Sciences Dresden

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Cover photograph: A farmer and a researcher walking and talking in the veld in the northern Succulent Karoo, South Africa.
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Biodiversity in southern Africa

Volume 3:

Implications for landuse and management

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Bundles of grass piled up alongside the road for trade in the Kavango. Photo: A. Gröngröft.

Part IV

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Causes and perspectives of land-cover change through expanding cultivation in Kavango

Michael Pröpper*, Alexander Gröngröft, Thomas Falk, Annette Eschenbach, Tobias Fox, Ursula Gessner, Judith Hecht, Manfred O. Hinz, Christian Huettich, Thomas Hurek, Fransiska N. Kangombe, Manfred Keil, Michael Kirk, Clever Mapaure, Anthony Mills, Robert Mukuya, Ndateelela Emilia Namwoonde, Jörg Overmann, Andreas Petersen, Barbara Reinhold-Hurek, Ute Schneiderat, Ben J. Strohbach, Melanie Lück-Vogel & Ulrike Wisch

Summary: With this interdisciplinary case-study we deliver an integrated analysis concerning the problem of expansive cultivation impacting on biodiversity in the dry Woodland Savanna of the Kavango Region of Namibia. We quantify and visualise the impact of cultivation on dry-forest species associations, deliver a description of existing vegetation and soil properties and their suitability for cultivation and possibilities for improvement. Likewise we look at the characteristics of human landuse, at the socio-cultural rules and norms that guide their utilisation of biodiversity as much as the cultural and economic incentives that guide individual landuse strategies. We further analyse the potential and limitations for institutional adaptations, including low-capital input and locally adapted agricultural intensification. By drawing such a broad picture from interdisciplinarity we assess the success of necessary policy recommendations and alternative options for managing the communal land of the Kavango Region.

1.1 Introduction

The magnitude of anthropogenic land cover changes through landuse, especially in the form of land-clearing for agricultural purposes, is one of the key drivers for global biodiversity losses (Klein Goldewijk & Battjes 1997, Klein Goldewijk et al. 2004, Turner et al. 1990). Worldwide it has been estimated that 6 million km² of forests and woodlands have been transformed into croplands between 1850 and 1992 (Ramankutty & Foley 1999). For southern Africa, large increases in the region's population and substantial pressures to accelerate economic development are being projected (Biggs et al. 2008). Resulting landuse changes due to agricultural expansion and livestock production are 'expected to remain the dominant driver of biodiversity loss in Southern Africa over the next century' (Biggs et al. 2008: 296f., Sala et al. 2000, Millennium Ecosystem Assessment 2005). Furthermore it is stated that 'the impact on land transformation in southern Africa is likely to have disproportionately high impacts on global biodiversity' (Biggs et al. 2008: 304).

An impact of human landuse is already clearly detectable in the sub humid Woodland Savanna of the Kavango Region in Northeast Namibia. The increasing expansion of agriculture and of livestock production, extraction of tradable resources, logging, fishing, increases in waste and pollution often cause a degradation of habitats and the over-exploitation of species (Ashley 2000, Biggs et al. 2008, Falk 2008, Fox 2008, Geist & Lambin 2002, Mendelsohn & el Obeid 2003, Pröpper 2009a, b, Strohbach & Petersen 2007, Yaron et al. 1992). Between 1943 and 1996 the size of cleared land in the Kavango Region increased from 26,140 ha to 94,550 ha (Strohbach & Petersen 2007). In this paper we will concentrate on **expanding cultivation** on communal land since it is a key reason for the loss of highly valuable local biodiversity.

Namibian communal land is "... vested in the State" (Republic of Namibia 2002). This state ownership is, however, only a restricted form of ownership (Hinz 1995). The government must administer communal land in trust for the benefit of traditional communities residing on such land (Republic of Namibia 2002). The clearing of fields is regulated under customary and statutory law. The allocation of land rights on such land for residential and subsistence farming purposes is done by traditional authorities and controlled by land boards (Republic of Namibia 2002). Traditionally as well as according to the Communal Land Reform Act of 2002 use rights to fields for cultivation are individualised (Falk 2008).

In the Kavango Region long term ecological sustainability is often neglected due to the need to secure short term food supply of a poor population, which largely, even though not exclusively, depends on subsistence cultivation. Another reason for unsustainable resource use is that many ecosystem services are not considered in the decisions of economic actors. Approximately 24,000 households are living primarily from agriculture, about four fifths of the regional population of more than 201,000 people (Mendelsohn & el Obeid 2003: 115, National Planning Commission 2003). Approximately two thirds of the whole Namibian population, which is comprised of about 1.8 million people, depend to a large extent on agricultural production, while the proportion of agriculture to the Namibian gross national product of 1998 was less than 7% (FAO 2001). This indicates that a large proportion of Namibians practice largely subsistence agriculture. Constituting processes for poverty reduction, establishment of democratic community structures (later also their decentralisation), gender equality, and reconciliation have proved quite problematic and have not yet been completed (see as well Government of the Rebublic of Namibia 2001: 1ff., 2004). Even worse, as in many parts of the world it has to be expected that contemporary biodiversity loss will first backlash on rural small hold landusers, which are the main dependants on the use of savanna ecosystems. Hence, the challenge lies in a mitigation of the biodiversity impact while improving food and livelihood security—the finding of possibilities to balance ecologically and economically sustainable development.

A first step for us will be to gain a more precise understanding of the status quo and the multiple driving forces of agricultural expansions. Poverty and population growth are certainly key drivers of tropical deforestation though not exclusively (Lambin et al. 2001: 262f.). Within Namibia, the Kavango Region has one of the lowest Human Development Indices with 0.55, a relatively high Human Poverty Index of 30, and a Gini-coefficient of 0.55, which is high even though below the average of 0.63 of Namibia as a whole (Republic of Namibia 2008, www.undp.org). The region has the highest incidence of poor people (56.5% in 2004) (cf. Sibeene 2008). In particular the poor are highly vulnerable to shocks such as droughts and floods, which threaten their subsistence income. According to the 2001 National Population and Housing Census (NPHC) only 11% of households throughout Kavango use electricity for lighting, 89% of households cook on open fires, 81% of households do not have sanitation (no toilets) and 38% do not have access to safe water (National Planning Commission 2003: 9).

In central Kavango a natural population growth of 1.5% has been estimated (Pröpper 2009a), which is considerable but modest compared to the Namibian average of 2.6% in 2001 (National Planning Commission 2003). Nevertheless the effective number of family labourers in general, and particularly in peasant farm households, can be expected to drop because of declining health caused by the HIV/AIDS pandemic (Fuller & van Zyl 2006, Hange et al. 1999). This development reduces agricultural productivity and thus threatens food security, particularly in rural areas (Pröpper 2009a).

Beyond that, the complex forces that Lambin et al. (2001: 263) identify such as changing economic opportunities linked to ‘social, political and infrastructural changes’ were studied. Besides operating with constraining conditions such as limited natural resources (soil properties, rain availability) and limited financial and physical capital, impoverished landusers utilise a) an endogenous set of traditional cultural knowledge on how to use the land for agriculture, as much as cultural convictions and institutions about land- and resource related rights, norms and duties, and b) operate within an institutional framework of state regulations, markets, rules and rights that involves other regional stakeholders and the Namibian state. The motivations and effects of such exogenous political and economic forces are influential in guiding the conservation of biodiversity. The scope and dimensions of this framework have to be suspected to be not fully known to the local farmers (Lambin & al. 2001).

One much discussed pathway of sustainable rural development is the increase of agricultural productivity in the entire north of Namibia. In the face of rural farmers’ quest for access to labour and cash markets, Mendelsohn & el Obeid (2003: 108) call rural development a ‘holy tenet’. They doubt that rural livelihoods in Kavango can be significantly improved on the basis of current production structures like too small farming plots, poor soils, low rainfall, prevalent diseases, lack of markets, labour- and capital-limits. They predict a strong trend towards upward mobility and urbanisation and conclude that those who decide to remain in the countryside “should not be abandoned but efforts to support them will be more effective if they are appropriately cast in terms of poverty alleviation rather than as rural development” (Mendelsohn & el Obeid 2003: 109).

In the face of currently extremely low agricultural productivity, which hardly ensures the satisfaction of most farmers’ basic needs neither human nor physical capital is accumulated. Such an accumulation would be, however, one precondition for economic growth. The Namibian state has not the capacity to outweigh this situation with a social security and insurance system. Hence, we challenge the simple prognosis of the incurability of the cultivation system by having a closer look again at the dynamics, impacts, drivers, and potentials for the cultivation system. We will focus on our micro-study field site as well as the economic and cultural background dimensions of cultivation decisions. We will assess the potential for agrarian reform as called for by Tapscott (1994), in particular for improved agricultural extension (Werner 2008) in order to train technical and management skills (Acquah & Davis 1997: 22ff.), strengthen farmers’ property rights and enhance their security, improve agro-processing and input supply, develop credit access, and support institutional capacity building, e.g. by developing marketing cooperatives. Our interdisciplinary micro-study analyses the causes and effects of biodiversity loss and economic stagnation within a complex socio-ecological system. The analyses support Namibian policy makers, extension officials, and development agents in improved decision making and raise awareness amongst a wider audience on the challenges in Kavango natural resource management.

1.2 Research site, setting, and methodologies

The core research area for this interdisciplinary multi-scale study is situated in the central inland of the Kavango Woodland Savanna, 65 km southwest of Rundu. In this area BIOTA has established two Observatories (Box 1; compare Volumes 1 & 2), Mile 46 and Mutompo (see blue boxes in Fig. 1). The territory around the Mile 46 Observatory (thin grey rectangular box) forms part of the Alex Muranda Livestock Development Centre (LDC) (formerly the Mile 46 LDC), and is a fenced government farm used for livestock breeding experiments. The adjacent area is managed communally and inhabited by several crop farmers’ and cattle holders’ villages.

These Kavango inland settlements are only a few decades old. Before this

Box 1

Within BIOTA natural and social scientists cooperated by comparing the dynamics of change measured by use of standardised methodology at standardised **Biodiversity Observatories**, which are exposed to different landuse types and were established along important environmental gradients, in order to assess the causes of changes. Observatories are fenceless research areas of 1 km² that are earmarked with GPS data to allow comparable research activities on an identical territory. During the planning for the first project phase of BIOTA, the Kavango Region was identified as a potential research area. In the course of the project's development, project planners were looking for fence-line contrasts, the outcomes of different landuse strategies on both sides of a fence that would be visible from the air or from a satellite. Fence line contrasts offer a good opportunity to investigate impact and consequences of different types of landuse from various perspectives. One contrast was identified at the livestock development centre Mile 46 in central Kavango.

people used to live exclusively along the Kavango River. Migration to, and establishment of, the inland communities of the Mutompo area have been driven by an exponential population increase and a resulting over-exploitation of resources along the river, which started in the early 1970s, and increased especially after independence in 1991.

In the early years of settlement people relied on non-permanent water holes. However, from the 1970s the first water holes were drilled and used with hand pumps. During the following decades most villages received diesel-driven water pumps and reservoirs (e.g. Mutompo in 1989) that raised the attractiveness of these settlements for further migrants (Falk 2008).

The villages consist of between 100 and 300 inhabitants, which use the woodland adjacent to the Observatories for extensive small scale cultivation, as well as for grazing and as a reservoir of timber and non-timber forest resources. These villages consist of households, which are the most central social and economic unit in Kavango society. As such they are permanent living- and working-collectives that accommodate one or more families or members of families inhabiting the homestead, which is the actual material locus. With the exception of very few roadside households villages are still without electricity. All households lack sanitation. People's homesteads consist of clay-huts. Farmers reach their fields by foot. Transport to inland settlements and fields occur predominantly by walking and using ox-drawn sleds.

The social-ecological systems have been analysed in the BIOTA Southern Africa research team comprised of anthropologists, botanists, economists, jurists, microbiologists, soil scientists, and remote sensors. Between 2000 and 2009 this team worked with different methodologies and on different scales as described below:

Anthropological long-term field research was executed in the five villages adjacent to the Observatory Mutompo (see Fig. 1) between 2003 and 2008 and concentrated on cultural aspects of land-use ranging from environmental knowledge and perceptions to the impact of different behaviours and landuse practices. A core method—an ethnographic census—was used in 2005 to gain an exhaustive picture of population structure and reliable figures on the demography of the population utilising the area around the Observatories. To assess the extent and the effect of human action on land, the presence of village and household members as actual users of a certain territory was identified to be one of the central components. Hence, the census sample uses a territory, which is shaped by natural borders like paths and roads surrounding the Observatory Mutompo as its framing element (the red line in Fig. 1). Defining such a territory offers the possibility of roughly calculating the use intensity for this particular piece of land, which covers about 9,000 ha and has been used at census date by 107 households that were cropping within the territory. This census was complemented with participant observation, open and structured interviews on all aspects of the farming system, and several surveys e.g. on field uses and agricultural input strategies, on gender related labour division and on household consumption patterns.

Agro-economic modelling concentrated on assessing long-term effects of farming strategies on degradation processes and food security. For this purpose a multi-annual programming and optimisation model (MAPOM) was developed. MAPOM is related to a typical village, which consists of two farm household categories. In general, it combines the theoretical conceptions of household economics and bio-economics and includes relevant bio-physical features. Primary and secondary data were collected with a case study on farming systems, which was conducted in the research area with semi-structured interviews (2005). Further, a review on region specific publications (grey literature) was related to economic aspects of the farming system. These data were used to identify relevant household activities and their input-output combinations. Predominantly three agricultural production sectors are taken into account a) crop production, b) livestock production, and c) natural resource production. Important input factors for crop production activities are for instance land and labour, while outputs are yields. MAPOM maximises village utility by determining the mixture and participation levels of households in these activities conditional to several restrictions. Apart from prevailing household activities even innovative activities like "improved livestock production" are considered. One peculiarity of MAPOM is that empirically identified preference-structures are used in the utility function in terms of weighting factors. To assess preference structure a Traditional Conjoint-Analysis (TCA) grounding on Lancasters assumption that utility of a good is deduced by its different factors (characteristics) (Tano et al. 2003: 5) was conducted in 2005. In this context a TCA is a methodological approach, which tries to estimate, on the basis of utility levels obtained with empirical surveys, the contribution of each factor to overall utility (Backhaus et al. 2006: 558). Households in MAPOM are a) equipped with several productive resources (labour, land), b) can supplement domestic production with purchases and c) have to meet a specific nutrition level. One of several scenarios simulates the impacts of a fee system for the usage of natural resources on trade-offs between food security and native biomass conservation. Describing and explaining MAPOM in its manifold aspects goes beyond the scope of this study. For details on a) the model conception, b) the used input-output combinations and c) the model components, consult Hecht (2009). Moreover, the results presented in the following chapters are predominantly related to crop production activities and are associated with the imposed model assumptions.

Institutional economic and **legal** analyses had the objective to assess the different aspects of the institutional framework including national policies, statutory and customary law as well as internalised informal conventions. It has been further elaborated how different institutional incentives influence, support and contradict each other as well as how effectively they influence the actual behaviour of farmers as well as of various natural resource management decision makers. For understanding the dynamics of agricultural cultivation in the Kavango Region the most relevant institutions are those, which regulate land, water and forest resources. The analyses started with a review of relevant legal documents as well as the available publications, with special emphasis on literature produced by Namibian scientists. On the basis of the desk research, traditional authorities, state representatives at national, regional and local levels, and local scientists were interviewed with semi-structured questionnaires. The analyses of these interviews formed the basis for surveys of farmers' perceptions on landuse regulations to assess the knowledge about and acceptance of statutory and customary laws as much as unconsciously followed internalised customs and habits that actually affect cultivation practices. Again, semi-structured questions were used to obtain a detailed picture of respondent's perceptions. Findings of the institutional analyses have been discussed and adjusted with various stakeholders and eventually made available to customary and statutory policy makers.

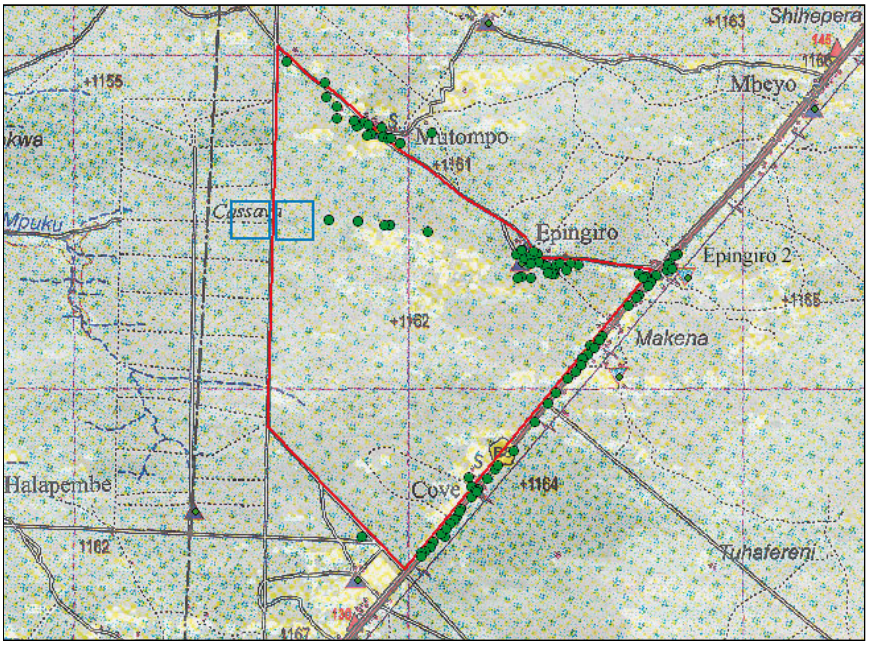

Fig. 1: The core research area with Observatories, villages and census territory. Red polygon = census territory, blue squares = BIOTA Observatories, green dots = households, in 2005. Source: Pröpper (2009a).

Remote sensing methods and **satellite image analysis** were employed for assessing land cover and vegetation distribution in the Kavango Woodland Savanna, and to monitor landuse changes and the dynamics of progressive clearing and subsistence cultivation. The main databases were satellite images of the Landsat series, which deliver spatial information on land surface characteristics since 1972. The first sensor MSS (Landsat 1) had a spatial resolution of about 80 m by 80 m. From 1984 onwards, the spatial resolution was improved to 30 m x 30 m by TM (Landsat 4 and 5) and ETM+ (Landsat 7). For the core research area (see Fig. 1), very high resolution Quickbird images were available for the 5th and 13th of April, 2007, with a resolution of 2.4 m in the multi-spectral bands and 0.6 m in the panchromatic band.

The vegetation of the dune and interdune systems of the central Kavango Region could be mapped and characterised by using Landsat data (Fox 2008, Strohbach & Petersen 2007, Vogel 2006) and in a multi-scale approach combining Quickbird, Landsat and MODIS data (Gessner et al. 2009, see also Volume 2).

For the monitoring of landuse dynamics and for the assessment of progressive clearing for cultivation, different approaches have been investigated, based on a set of Landsat data acquired between 1984 and 2008. Vogel (2006) used an approach of bi-temporal change detection, by combining changes in the spectral bands with shape parameters of the changed regions to separate landuse induced changes from changes caused by other drivers. Another remote sensing approach was used to create time series, which show the clearing of natural vegetation from 1984 to 2008. A rule based classification was performed for six Landsat scenes, using grey-level thresholding, especially in the short-wave infrared bands 5 and 7 of Landsat TM (Fox, 2008), to derive the deforestation history. Further evaluations were done to differentiate landuse, fallow, and succession states in former cleared and cultivated areas.

Botanical vegetation data were gathered following the Braun-Blanquet sampling methodology, with the aim to describe and map the vegetation types in the area. In this procedure, 50 x 20 m plots were located, and the species composition and abundance (as visually estimated crown cover) determined. In addition, habitat description data e.g. GPS location, soil type, disturbance were also collected. A total of 153 plots were surveyed in February–March 2003. The data were analysed by classification and ordination techniques using multivariate statistical software. The resulting vegetation units were mapped using remote sensing applications.

For the assessment of the **diversity and activity of microorganisms**, mainly culture-independent methods were developed, as most environmental strains defy cultivation; additionally, classical cultivation techniques were applied. As Kavango soils are rather nutrient and especially nitrogen poor, a main focus was on nitrogen-fixing bacteria. For the detection of major nitrogen-fixing microorganisms in natural environments direct targeting of *nifH* genes by PCR with universal primers is the method of choice. Culture-independent molecular ecological studies based on sequence analysis (Hurek et al. 2002), denaturing gradient gel electrophoresis (DGGE) (Demba-Diallo et al. 2008), and fluorescently labelled Terminal Restriction Fragment Length Polymorphism (T-RFLP) (Knauth et al. 2005) of *nifH* DNA or mRNA fragments were developed and refined further (Burbano et al. 2010). To allow a rapid characterisation of diverse communities in the natural environment, quantitative comparisons with high-throughput, high-coverage arrays—microarrays—are of advantage, especially when targeted to functional genes in order to estimate functional diversity. Oligonucleotide probe-based microarrays can discriminate diverse groups more specifically, while a large set of probes needs to be designed to achieve a high coverage. We therefore developed a *nifH*-based oligonucleotide microarray (*nifH*-diagnostic microarray) as a rapid tool to effectively monitor nitrogen-fixing diazotrophic populations in a wide range of environments (Zhang et al. 2005, 2007). Total bacterial biomass was determined by improved epifluorescence staining of bacterial cells.

The effect of landuse and soil type on the composition of bacterial communities was assessed by comparative and high resolution DGGE-fingerprinting of bacterial 16S rRNA genes (Gich et al. 2005, Zul et al. 2007). In order to get insight into the interrelation of landuse and soil type on the microbial transformations of soil organic matter, stable carbon and stable nitrogen analyses were conducted. Laboratory mineralisation experiments of soil organic matter were carried out to investigate the potential of different soils for nitrogen and phosphorus regeneration, and the associated key reactions of microbial mineralisation were then studied based on exoenzyme activities and using techniques established for complex soil matrices (Coolen & Overmann 2000). Finally, multivariate statistical approaches served to identify relationships between landuse and soil nutrients, bacterial biomass and diversity, and bacterial nitrogen turnover.

The sampling campaign for the **soil assessment** took place in March 2007, at the end of summer and the rainy season respectively, on or close to crop fields of the village Epingiro. Additionally some fields of the adjacent village Mutompo and pristine sites at the Mile 46 national livestock development farm were sampled. Overall, 116 mixed topsoil samples were taken, by mixing nine samples of an area of 10 m^2.

For the setup of sampling, a scheme was developed categorising acres regarding parameters of landuse and suspected fertility. The soil was classified by colour into three categories (dark, medium and pale), assuming a dependency between colour and fertility indicated earlier by Petersen (2008) on the nearby BIOTA Observatories Mile 46 and Mutompo as well as by local knowledge. The landuse classes were categorised into pristine, acres and fallows based on satellite pictures and aerial photographs respectively of 1971, 1996, 2004 and 2007 in correspondence with local guides. Laboratory analyses of samples followed standard procedures of the BIOTA project (see Volume 1, Part II). The leaf tissue analysis was conducted by the Ministry of Agriculture, Water and Forestry in Windhoek, Namibia (after Mills & Jones 1996, Richards 1993).

1.3 The status quo of the cultivation system

The cultivation system that farmers in the research area apply can be summarised as rain-fed, labour-intensive, small-scale agriculture with dominant subsistence elements and very little capital input (see as well Falk 2008, Mendelsohn & el Obeid 2003, Pröpper 2009a). Traditional knowledge and traded labour skills play an important role in applying cultural strategies of cultivation.

Since pearl millet is known for its low demands in terms of soil quality and rainfall, it is the main staple crop, followed by maize (Pröpper 2009a). Millet is grown in distant fields, which are located in inter-dune valleys. Gardens located near homesteads are used to cultivate legumes and cucurbits. These are often intercropped with maize and sorghum. Non-food cash crops such as jatropha, cotton, or tobacco have not been cultivated in the study area (Pröpper 2009a).

Traditionally, as well as due to the lack of capital and transport, fields in the central Kavango are not irrigated. Likewise herbicides are not used to deal with the significant weed problem, nor are pesticides and fertilisers being applied. Also, there is little protection from bird predation of the crops. About 90% of farmers in the research area use ox-drawn steel ploughs, but do not practise shifting cultivation, since people stay on one plot as long as possible and expand fields along the edges. Crop rotation or strategic fallow periods are also uncommon.

Cropping methods differ between individual farmers depending on the availability of land, seeds and personal preferences. A general rule that was expressed and seems to be followed by most farmers is that “maize likes growing on its own” and that “millet will take the power from the maize”. Likewise legumes with a high N-fixation are planted “if the soil is not strong” (Pröpper 2009a).

Table 1: Frequency of crops planted by independent field owners in 2006 (*N* = 145)

Crop (pl./common den.)	Common name	Scientific name	Users	%
Mahangu	Pearl Millet	*Pennisetum glaucum*	143	99
Epungu	Maize	*Zea mays*	138	95
Makunde	Cowpea	*Vigna unguiculata*	113	78
Nongomene	Bambara nut	*Vigna subterranea*	80	55
Ilyia	Sorghum	*Sorghum bicolor*	56	39
Nondongo	Peanut	*Arachis hypogaea*	39	27
Katjama	Melons	*Citrullus lanatus*	36	25
Etanga	Pumpkins	*Cucumis africanus*	32	22
Nomusipo	Sugarcanes	*Saccharum officinarum*	20	14
Tombo	Sorghum	*Sorghum bicolor*	14	10
Mutete	Wild spinach	*Hibiscus sabdariffa*	6	4
Rupotera	Pumpkins	*Cucumis metuliferous*	6	4
Maliangwa	Pumpkins	*Cucurbita pepo*	2	1
Total fieldowners			145	100

Kavango farmers distinguish five seasons (autumn, winter, spring, early summer, late summer). Additionally, according to the availability of crops beginning with the harvesting season in March, the year is divided into two halves, the one of hunger (Nzara) and the one of well-being (Ewogo). The clearing—kututura—of fields takes place predominantly in the spring months of September and October and is done manually by men using axes and hoes. Farmers usually spare fruit or shade trees, which are left standing. The cleared material is either used as fencing material around the fields, as firewood or it is piled up for a drying period to be burned on the spot. Burning as a clearing strategy is forbidden in the Kavango. Human burning activities, which get out of control and cause widespread fires have been named frequently as the cause of biodiversity losses (cf. Vogel 2006: 152). Additionally, frequent fires promote the development of impenetrable thickets (Strohbach & Petersen 2007: 398) and cause a reduction of soil fertility by burning organic litter that would otherwise decompose into organic nutrients (Mendelsohn & el Obeid 2003: 68f.).

The ploughing and sowing season starts independently of the start of the rainy season, during November. Traditional and improved kinds of seeds are known, and are distinguished according to appearance, taste and performance. Seeds are sown by women using a range of different techniques immediately after ploughing. Next to the main staple crops millet and maize, various traditional crops and vegetables are usually planted (see Table 1). Weeding, as the most labour-time consuming component of crop production, is necessary due to the heavy spread of grasses such as *Tricholaena monachne* (Esusu) or *Schmidtia pappophoroides* (Erarampi) on fields. Weeding is mainly carried out with hand tools (hoes). Both men and women do the weeding. From June to mid August fields of the main crop are harvested. Harvesting is done manually. The main crops are harvested by both men and women. Threshing can be further separated into a male and a female specific task. Male household members usually conduct the 'main' threshing process, while females are responsible for separating the grain from its sheaths. Though labour is commonly pooled in a household, internal labour shortages appear as soon as all male producers are absent during the ploughing period, e.g. in search of off-farm employment (Mutwamwezi & Matsaert 1998: 8f.) or due to diseases. Under such circumstances, ploughing activities have to be carried out by women as well.

1.4 The dynamics of expanding cultivation

Early settlement of the Kavango Region occurred exclusively along the Kavango river terrace while the area inland of the river has been settled only during the last few decades. Over-exploitation of resources along the river and the construction of a trunk road (B8) between Grootfontein and Rundu in the 1970s triggered the development along this main road. At that time, the South African Defence Force cleared a strip of natural vegetation along the B8 for security reasons, which was initially used for cultivation by the local population (Strohbach & Petersen 2007).

Between 1943 and 1996, the cultivated area increased from 0.5% to 4.0% of the total Kavango Region (Mendelsohn & el Obeid 2003: 108) and between 1990 and 1995, the annual rate of deforestation was estimated to be 0.3% (Hailwa 2002). These trends found in official statistical data are supported by the analysis of remote sensing data acquired since the 1970s. In addition to mere numbers, remote sensing analyses have given evidence of the spatial patterns of cultivation dynamics, and have delivered further information on, fallow lands and on the affected vegetation types.

A comparison of Landsat data of the years 1991 and 2000 clearly depicts the expansion of settlements and agriculture in dune and inter-dune areas, with the trunk road B8 and the rivers (mainly Okavango river and its tributaries) functioning as major axes of development. Fig. 2 shows the spatial patterns of cleared land in the central Kavango Region for the years 1991 and 2000 in purple and green colours respectively. For a rectangular area spanning 50 km to the north-west and to the south-east of the road (see black box in Fig. 2), spatial buffer statistics were calculated, and results are illustrated in Fig. 3. According to this buffer analysis, the major cultivation and settlement areas in 1991 are located in a zone about 10 km wide to the north-east of the road. To the south-east of B8, clearings are less abundant and generally found closer than 5 km to the road. Reasons for this might be the deeper Kalahari sand towards the east, where the fertile soils of the inter-dune areas are less abundant

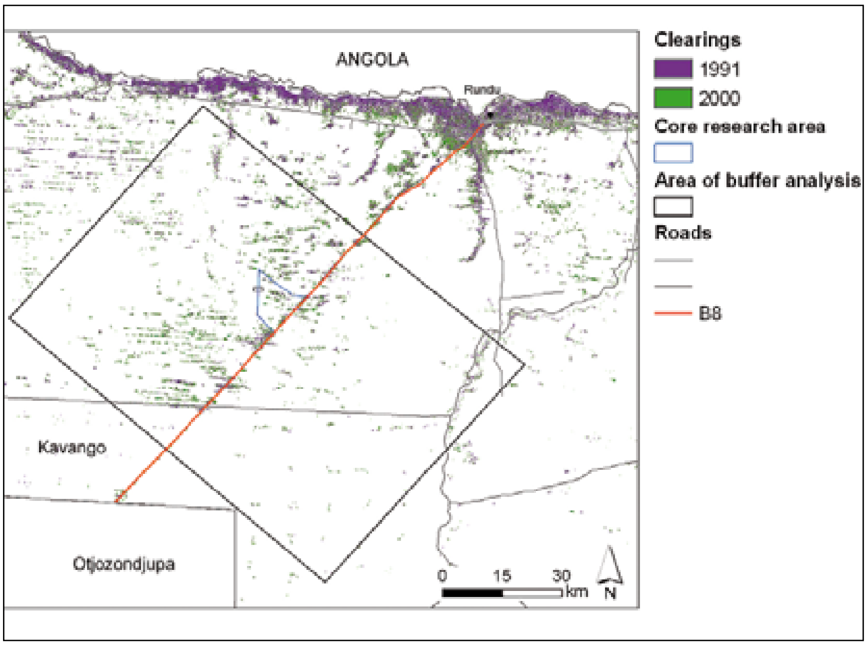

Fig. 2: The spatial extent of clearings in the central part of the Kavango Region for the year 1991 (in purple) and further expansions until 2000 (in green). A buffer analysis was performed along the road B8, for the area marked by the black rectangle.

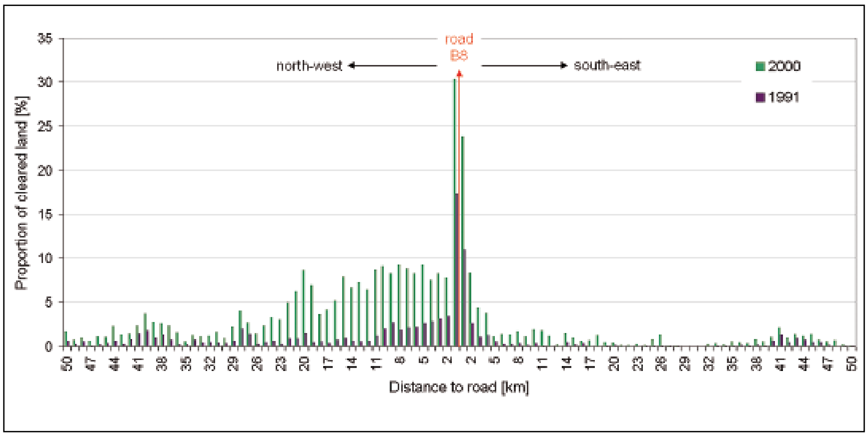

Fig. 3: Result of the buffer analysis along the road (B8) within the area marked by a black rectangle in Fig. 2. The graphic shows the enormous expansion of clearings between 1991 and 2000 especially in a strip approximately 30 km wide north-west of the B8. Each bar represents the proportion of cleared land within a 1 km wide strip of land.

as much as the growing distance from Rundu and transaction costs, which are incurred to reach Rundu. In a distance of approximately 38–48 km north-west and south-east of the road, clearings are again more frequent and seem to be caused by settlements and agriculture along tributaries of the Okavango River namely the Mpuku and Omatako omiramba. During the decade from 1991–2000, agricultural landuse patterns became denser in those areas, which had already been settled in 1991 but major transformations of natural vegetation occurred at distances up to 30 km north-west of B8. The core research area of this study is located in this area where agricultural expansion has been greatest in the region. In 2000, 8.6% of the natural vegetation had been cleared in a strip 30 km wide to the north-west of the B8.

The deforestation history has also been analysed with higher temporal detail for a smaller area of the Kavango Region by Fox (2008) (Fig. 4). This analysis completely covers the core study area (marked in blue) and also the unsealed roads connecting the villages of Epingiro, Mutompo, and the Alex Muranda LDC. Again, early clearings can be observed near the main road B8, with some other old clearings following the tributary river (omuramba) Mpuku in the northern part of the map. Especially in the southwestern part, the younger cleared areas exhibit the elongated west–east striking patterns following the dune and inter-dune system. In additional analyses the identified cleared areas were combined with former vegetation cover. It was found that mainly the slopes and transition zones between dune crests and inter-dune areas were used for cultivation (Fox 2008).

With regard to the leaching of the soils by cultivation, it is important to estimate the duration of agricultural use and to assess the extent of fallow land and the succession states up to secondary shrub and tree vegetation. As no clear distinctions can be performed between densely covered cropped fields and fallow land using (mono-seasonal) Landsat data, three categories of current and formerly cleared and cultivated areas were classified (Fox 2008). The results for the years 2000, 2004, and 2008 are shown in Fig. 5 for the core study site around Mutompo and Epingiro. The re-growth of secondary vegetation can be observed e.g. south of the village of Mutompo. For the background of the representation, the red spectral band of the corresponding Landsat scene was used. This provides information on the density of vegetation cover and shows the influence of bush fires over time (which were stopped by the cut-lines of the LDC).

1.5 Biodiversity status quo and potentials

Cultivation impacts on the Woodland Savanna vegetation

In a next step we assess the measurable status quo of biodiversity in the study area including that of the soils and micro-organisms. This analysis will focus not only on current landuse impacts, areas of threat and priorities for conservation but also on potential input and improvement scenarios.

With two different main soil types present in the study area, two main vegetation types can be distinguished: The Thornshrub Savannas (*Acacietea*) are found on the heavier Haplic Arenosols of the inter-dune streets. The density and composition of these *Acacietea* depends on the clay/loam content of the soils from the extremely dense *Acacia luederitzii-Croton gratissimus* thicket association to the more open, better accessible *Eragrostis rigidior-Acacia fleckii* bushland association and *Bauhinia petersiana-Acacia fleckii* shrubland association. The latter forms a transition to the typical Kavango woodlands (the *Burkeo-Pterocarpetea*), with the *Pterocarpus angolensis-Guibortia coleosperma* woodland/thicket association being the typical form of these woodlands associated with the remnants of the expansive dunes (Burke 2002, Strohbach & Petersen 2007).

Cultivation especially the clearing activities of farmers done manually or with the use of fire can have a significant impact on the vegetation. Strohbach & Petersen (2007: 395ff.) found that especially the *Eragrostis rigidior-Acacia fleckii* bushlands and the *Bauhinia petersiana-Acacia fleckii* shrublands are targeted by field clearing activities. *Eragrostis rigidior-Acacia fleckii* bushlands are somewhat structurally and by substrate similar to the *Bauhinia petersiana-Acacia fleckii* bushlands associations. It was further found that the accumulated cover of these associations in their study area sample has already been reduced to only 4.6% of the area. Yet these associations harbour about 40% of the species richness (between 55 and 80 species per 1000 m^2) of the study area (Strohbach & Petersen 2007: 399). The relatively small geographic extent of these communities renders them an even bigger conservation priority because they are at absolute risk of complete transformation into cropland. This will put other community types at risk as well, as it becomes more difficult to find patches large enough to establish crop fields with ever-increasing demand for crop production. These associations also present the best grazing value for livestock by harbouring highly palatable species such as *Brachiaria nigropedata*, *Digitaria seriata* and

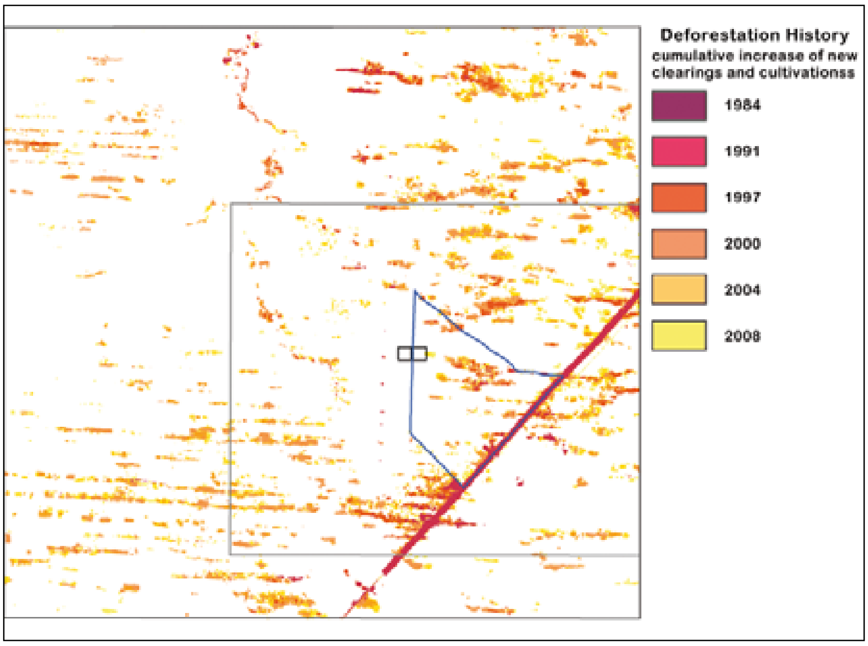

Fig. 4: Development of deforestation in a sub-section of the Kavango Region around the Observatories of Mutompo and Mile 46. Shown is the increase of cleared areas in the period 1984 to 2008, which is derived from Landsat data. The black rectangle marks the detail shown in Fig. 5.

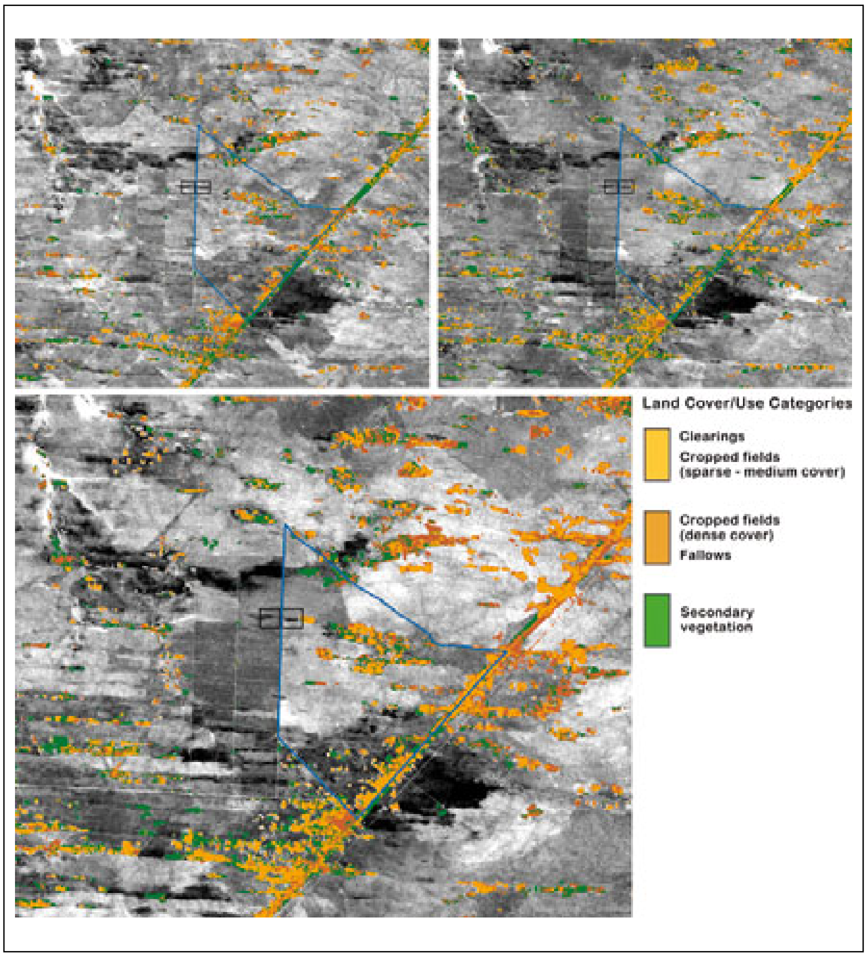

Fig. 5: Status of cultivated and formerly cultivated fields in the area of Mutompo/Epingoro, classified by Landsat data of 2000 (upper left), 2004 (upper right) and 2008 (large picture). In the background, the visible red band (band 3) of the respective Landsat scenes is displayed in greyscale.

Photos 1–4: Typical examples of the vegetation types found in the study area. Top left: impenetrable thickets of the *Acacia luederitzii-Croton gratissimus* association. Top right: open *Eragrostis rigidior-Acacia fleckii* bushlands. Bottom left: Bush- and shrublands of the *Bauhinia petersiana-Acacia fleckii* association. Bottom right: typical *Pterocarpus angolensis-Guibortia coleosperma* woodlands and thickets form the expansive Kavango woodlands.

Photo 5: The exact origin of the *Acacia fleckii-Terminalia sericea* closed shrublands and thickets are not known. They could be remnants of abandoned fields or the results of extreme fires, which destroyed the woodlands in the past. The position of these shrublands and thickets in a theoretical successional sequence suggests both factors as potential causes.

Schmidtia pappophoroides (Strohbach & Petersen 2007). Clearing for agriculture not only impacts on biodiversity but also on successional processes and grazing quality of the vegetation.

The *Eragrostis rigidior-Acacia fleckii* bushlands are preferred cropping areas, as these are relatively easy to penetrate and clear, compared with the near impenetrable *Acacia luederitzii-Croton gratissimus* thickets. They also have a relatively fertile soil, compared with the transitional soils of the *Bauhinia petersiana-Acacia fleckii* shrublands and the pure (and poor) sands prevailing as substrate in the *Pterocarpus angolensis-Guibortia coleosperma* woodland/thicket association.

The findings of the soil science team that dark soils are preferred for cultivation is supported by the fact that the *Eragrostis rigidior-Acacia fleckii* bushlands and *Bauhinia petersiana-Acacia fleckii* bushlands are found on those dark clayey and loamy soils. Furthermore Strohbach & Petersen (2007) assume that degradation in the form of dense encroachment in the *Acacia fleckii-Terminalia sericea* shrubland and thicket association is caused by abandoned fields and/or the lasting impacts of severe fires, clearly a consequence of former uses (Strohbach & Petersen 2007: 397f.).

The impact of fire

The various pressures of landuse on natural vegetation are intensified by frequent bush fires (Strohbach & Petersen 2007: 391). Each year, considerable areas of the Kavango Region are affected by fire. The interpretation of data recorded by the satellite NOAA revealed that an average of 51% of the total area of north-eastern Namibia (including the Caprivi Strip) burnt each year between 1996 and 2000 (Mendelsohn 2002). Verlinden & Laamanen (2006) analysed Landsat satellite data and found that for the 1989–2001 period, on average 38% of the area of the Kavango and Caprivi Regions burnt annually. One reason for the comparatively high numbers given in Mendelsohn (2002) could be scale effects regarding the coarser resolution of NOAA and the higher resolution of Landsat data. Unfortunately both studies do not give individual numbers for the Kavango Region. However, for the Kavango Region (excluding the Caprivi Strip) the area burned in the years 2000, 2002, 2003, and 2005–2008 was analysed using a time series derived from MODIS data (MODIS standard product MCD45A1). In this analysis the years 2001 and 2004 had to be excluded as considerable data gaps in the MODIS burnt area products would have distorted the yearly statistics (see Figs. 6 & 7). The results show slightly lower, but nevertheless noticeable fire impact in this area and period, partly also dependent on the landuse systems in the Kavango (compare with Fig. 8). On average, 19% of the Kavango area was affected by fire in these years (Fig. 7). In total, 59% of this area burnt at least once, and 22% of the total area burned at least three times during these seven years.

The reasons for bush fires are manifold but the major part is of anthropogenic origin. In the central Kavango fire is used for cooking, clearing, felling large trees, stimulating grass growth, debushing, cleaning around homesteads, and chasing wildlife e.g. snakes. Beyond that, fire is closely related to cropping activities, as it is used for initial clearing of agricultural land and for burning crop residues on fields (Falk 2008, Pröpper 2009a, Werner 2002: 14).

It is beyond question that human induced fires, which get out of control and which mainly occur during the dry winter months, have a strong impact in the vegetation and biodiversity of the Kavango Region (Mendelsohn & el Obeid 2003: 68f.). Fires are considered one of the main drivers of vegetation change in the Kavango Region (Strohbach & Petersen 2007: 391). The effect of fire prevention on vegetation becomes apparent at the Alex Muranda Livestock Development Center (LDC), which is located in the West of the core research area (Strohbach & Petersen 2007). Alex Muranda LDC is equipped with cutlines (i.e. firebreaks) along its eastern border and along the central passage spanning from North to South. Fires originating from the cultivation area of the core study site frequently spread westwards driven by the dominant easterly winds and are usually stopped at the outer or the inner cutline of Alex Muranda LDC. Field surveys of Stroh-bach & Petersen (2007) found a clear structural difference between areas inside and outside of the LDC with shrub cover of *Pterocarpus angolensis-Guibourtia coleosperma* woodland and *Acacietea* vegetation types being lowest outside the LDC and highest in the western part inside the LDC. Fire may therefore be an important factor maintaining the more open woodland system by preventing bush thickening (Strohbach & Petersen 2007). Fires may also play an important role in the nutrient cycles of the system by returning nutrients to the soil, thus aiding in soil

Photo 6: A typical mahangu field (pearl millet) after being cleared out of the *Eragrostis rigidior-Acacia fleckii* bushlands during the previous season.

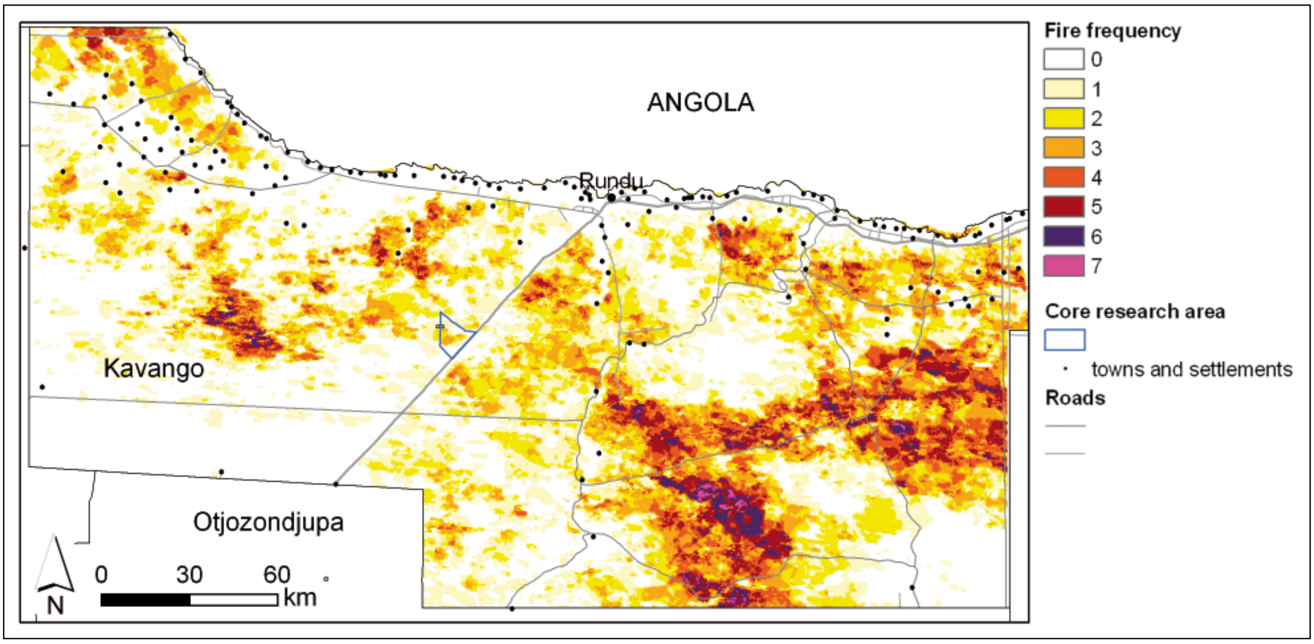

Fig. 6: Frequencies (number of years) of bush fires in the Kavango derived by MODIS time series data from the years 2000, 2002, 2003, and 2005–2008.

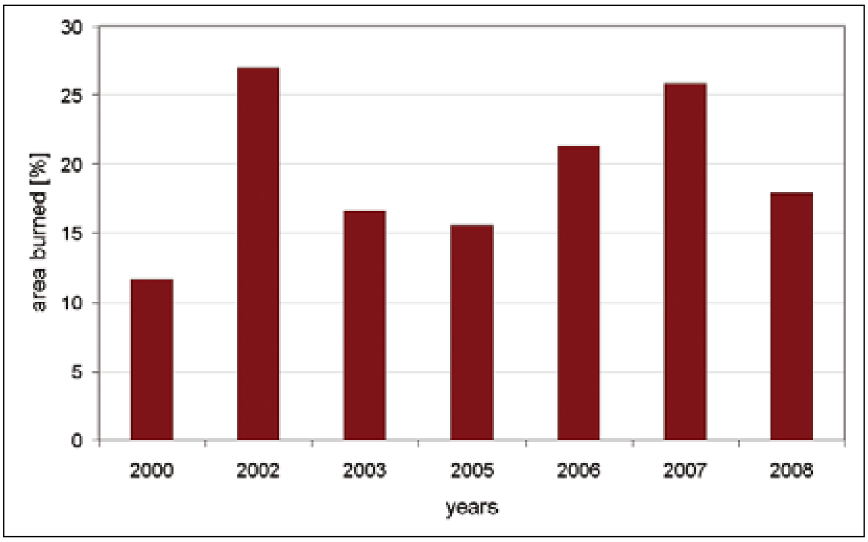

Fig. 7: Percentage of fire affected areas in the Kavango, derived by MODIS time series data, for the years 2000, 2002, 2003, and 2005–2008.

fertilisation for crop production but accelerating the leaching potential.

These results could be supported by remote sensing techniques: According to satellite data analyses, the average cover of woody vegetation (excluding cultivated areas) was found to be 25% outside the LDC, adjacent to the Eastern cut line. In comparable areas inside the Alex Muranda LDC Mile 46, woody vegetation covers 35% behind the first cutline and 44% in the least fire affected areas behind the second cutline. The high shrub densities, which establish when fire is completely excluded are regarded as being detrimental to the grazing resource in the Kavango Region (Strohbach & Petersen 2007) indicating that moderately frequent fires are important for the maintenance of ecologically and socially sustainable Kavango ecosystems.

Other threats to the vegetation

Illegal hardwood harvesting, both for construction and carvings, form a major threat to the integrity of the woodland ecosystem in the Kavango Region (Pröpper 2009b, Pröpper & Gruber 2007). *Pterocarpus angolensis, Baikiaea plurijuga* and to a lesser extent *Guibortia coleosperma* are especially threatened by wood harvesting. *Baikiaea plurijuga* is a preferred construction wood species, and is even harvested for fencing posts at the Alex Muranda LDC. This species has been found to be relatively rare in the direct vicinity of the LDC, especially immediately adjacent to the fences. *Pterocarpus angolensis* is widely used as timber for construction, furniture making and carvings. Illegal harvesting is widespread, with small pickups travelling through the area, picking out single, straight trees, which are felled and the main trunk removed (Photo 7). This unsustainable harvesting of both *Baikiaea plurijuga* and *Pterocarpus angolensis* has led to the declaration of them as being "Near Threatened" according to the IUCN Red List Categories version 3.1 (2001) (Loots 2005).

Crop soils: water, nutrients

The soils of the study area all developed from relict dunes of the Kalahari basin, which were formed at least 21 ka years ago (Thomas et al. 2000). In Figs. 4 & 5 the east-west leading linear dune-field structure is clearly visible and also on the ground, in many parts of the basin a distinct dune/inter-dune topography is evident. Within the study area the typical dune morphology, even though still visible on satellite images, is nearly levelled and the area of former dunes has been eroded sometimes to a level even lower than the inter-dune streets. Another characteristic feature indicating the erosion of the

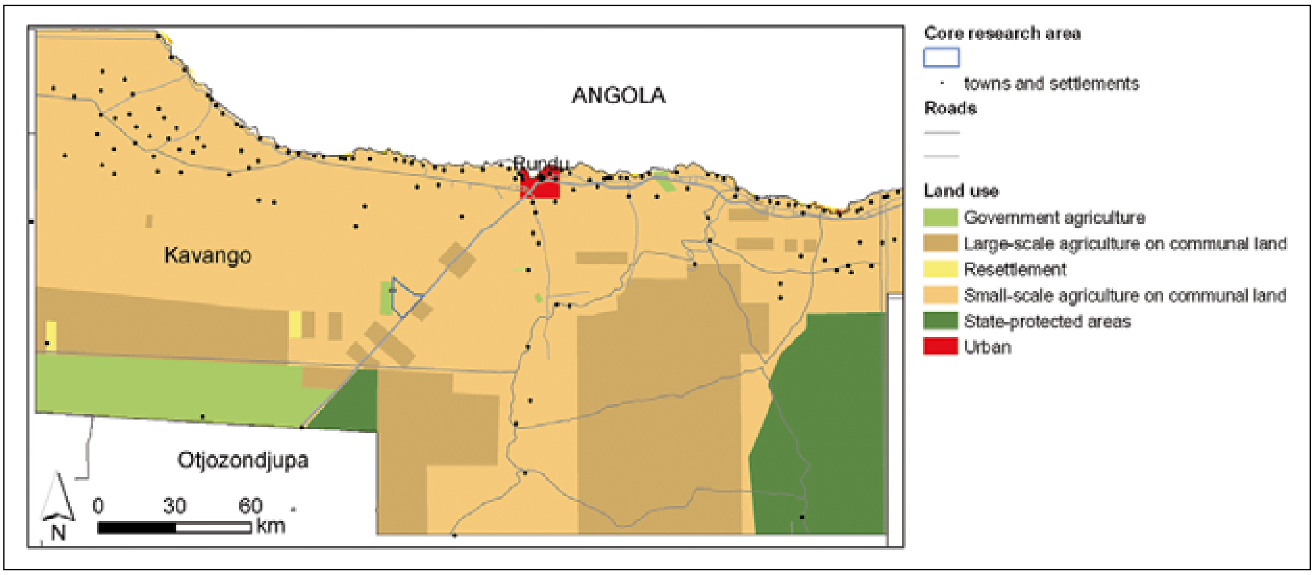

Fig. 8: Landuse systems in the Kavango.

former system is the ‘omiramba’. These are seasonally waterlogged depressions, which disrupt the regular dune structures from south-east leading north-north west (visible in the left northern part of Fig. 5). In the study area the mean spacing of the dunes is about 1.1 km in which the inter-dune streets amount to about 34.4% of the landscape. Whereas the dunes and inter-dunes can be distinguished by their vegetation structure without difficulty, west of the village Epingiro four inter-dunes merge, thus making dune/inter-dune differentiation uncertain in this area.

Because of their aeolian origin, all soils of the study region have been developed in deep sands and have a texture dominated by medium and fine sand. The soils can be divided into two main groups (dune and inter-dune) based on their broad topographic position in the landscape. With only a few exceptions they can all being classified as Arenosols. Within the dune area the pristine soils are strongly acidic and of very low nutrient reserves. For the inter-dune soils, however, a lower acidity, a slightly increased clay content, a reddish or dark brown or even gray colour and an enriched nutrient content is typical. Here, in the subsoil some calcium carbonate regularly occurs, which in some parts of the region surfaces as massive calcretes.

The inter-dunes are the locally preferred soils for cultivation and cropping and are called ‘ndombe’ by the local population. They are classified as soils with a capacity for “holding the water very long” and for staying fertile for up to 20 years. If yields decrease, soils are commonly described by local people as “getting old and tired” and are left fallow (Pröpper 2009).

A typical soil for cultivation is the brown inter-dune soil, classified as Haplic Arenosol (Eutric, Greyic) (Photo 8). Its texture has a clay content increasing with depth up to 8% and a constant silt proportion of about 5%. The sand fraction consists of medium and fine sands in equal proportions. The pH is only very slightly acid over the entire profile (about pH 6). The content of organic carbon of around 0.4% remains constant with depth. This is also true for the electrical conductivity, which is at about 12 $\mu S\ cm^{-1}$.

Photo 7: An example of a *Pterocarpus angolensis* tree, which has been felled illegally. A piece of the trunk, ca 3 m long, is removed, whilst the remaining wood is left.

The concentration of water extractable ions is very low at 5 $mmol_c\ kg^{-1}$ while that of exchangeable cations ranges from 40 $mmol_c\ kg^{-1}$ in the topsoil to 60 $mmol_c\ kg^{-1}$ in the subsoil, reflecting the increasing clay content. The fertility of the soils of the landscape is described in more detail below (for details see also Wisch 2008 for additional information):

Photo 8: Typical inter-dune crop soil.

- The pH_{H2O} values of the majority of topsoil sample profiles lie between 5.5 and 7.5. This is, according to Landon (1991) a medium range, optimal for most crops and not restricting the availability of any essential nutrients. Soils found on dunes are in a lower pH range, brownish and greyish inter-dune soils are intermediate while the dark and loamy soils lie in the upper end of the range, which is a result of the calcareous subsoil. It can be generally stated that despite the soil’s sandy texture, there is no acute danger of acidification and thus aluminium toxicity in the inter-dunes. However, a pH above 7 can be a disadvantage, as it can potentially lead to deficiencies of phosphorus and some micronutrients.
- The typical content of topsoil organic carbon ranges between 0.25 and 1.22%, which is regarded as ‘low’ or ‘very low’ (Landon 1991, Pagel 1982). Within the dune soils, the organic carbon content declines with depth to 0.1%. This is in contrast to the inter-dune soils where the soil organic matter stays at a relatively elevated level down the profile to a depth of 1 m. In the ‘omuramba’, local sites with elevated contents of organic carbon (e.g. topsoil values of 0.6%) are present, which is caused by the humus stabilising properties of

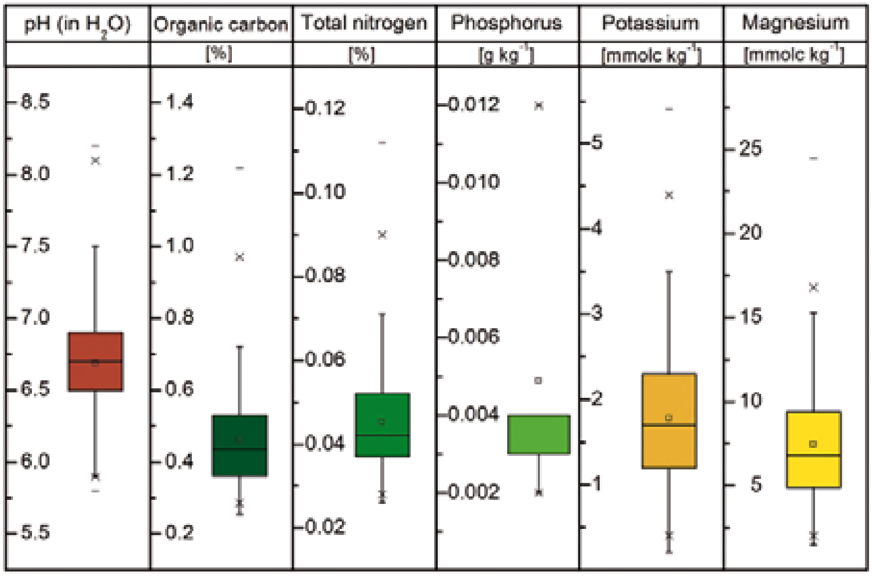

Fig. 9: Soil chemical data of the topsoil.

soils rich in carbonates (Oades 1988). If one balances the organic carbon across the soil to a depth of 1.5 m, then it can be calculated that the bright dune soils have accumulated only about 3.7 kg m^{-2} soil organic carbon, whereas typical inter-dune soils range between 7 to 12 kg m^{-2}.

- In the topsoils, total nitrogen ranges, albeit always low, between 0.03 and 0.16%. Within the inter-dunes, the lower C/N-ratios (9–10) than in the dunes (13–14) indicate an improved N availability. This difference suggests to the fact that the total nitrogen accumulation in the soils of the landscape is even more variable than the content of organic carbon (0.28 kg m^{-2} in dunes, up to 1.3 kg m^{-2} in inter-dunes). Just as organic carbon, in the case of nitrogen content the majority of topsoil values are rated as 'very low' or 'low' by Landon (1991) or Pagel (1982) respectively. However, 26% of the samples may be rated as 'medium' and 3.4% even as 'high' (Pagel 1982), which shows the high variability in total nitrogen content in the region.
- The amounts of total phosphorous are very low. In most cases, an analysis of plant available P resulted in values below the limits of detection (< 1 mg kg^{-1}). The sites with the highest values of available P (4–8 mg kg^{-1}) coincided with those with the highest nitrogen contents. The majority of the sites where available phosphorus could be detected were located near trees or in dense shrub thickets. This effect of slight P enrichment under trees and shrubs as well as on former tree-dominated sites was also reported by Hebel (1995).
- The exchangeable cations occur largely in concentrations in the medium to low range and in general soils do not appear to be highly deficient in these elements. Concentrations of exchangeable potassium are at a 'medium' range between 0.2 and 5.5 mmol$_c$ kg^{-1} (Landon 1991, Peverill 1999, FSSA 2007). Although the concentration of magnesium is higher with values between 1.5 and 16.8 mmol$_c$ kg^{-1}, the majority of sites may still be rated as having 'medium' levels (FSSA 2007, Landon 1991). The concentration of exchangeable calcium, ranged between 6 and 66 mmol$_c$ kg^{-1} and is slightly higher than the other elements. Only 11% of the sites may be classified as having 'low' concentrations of cations while 89% may be described as having a 'medium' concentration of cations (FSSA 2007, Landon 1991). Nevertheless, one has to keep in mind the high natural variability of soils due to the topography, in which the cation reserves vary strongly. Hence on some clay-poor soils high deficiencies can be found.
- In contrast to the pristine vegetation, for which deep tree roots guarantee the water up-take of plants even on soils with low water holding capacity, the cultivated crops strongly depend on sufficient water availability within the rooted upper part of the soil. Therefore, the difference in the available water holding capacity between the sites is of additional importance for crop growth. For the dune sites, the water holding capacity is about 60 mm for the uppermost 1 m of the soil while for sites within the inter-dune areas the value is up to two and a half time as much (about 160 mm).

Due to the cultivation and cropping activities, which started in some areas in the 1970es, some shifts in soil properties could be analysed based on a parallel sampling of cultivated and uncultivated soils in the year 2007. Results of this research suggest that over time the following main changes occur within the soil profile:

- The amount of organic carbon is reduced significantly (Fig. 10), which is a typical effect when pristine areas are converted to croplands (Post & Mann 1990, Hartemink 2006). Although the former topsoil contents were unknown and had to be calculated from pristine sites with comparable properties, the reduction was nearly 50% for the dark and nutritious sites and about 10% for the bright sandy sites. The comparison between cultivated fields and fallow land did not result in clear evidence of the recovery of the soil carbon content.
- With the loss of organic carbon a reduction in total nitrogen of nearly 50% also occurs in the dark and loamy soils. In the poor sandy soils, there is an increase in total nitrogen of about 20%, presumably due to the common practice of inter-cropping nitrogen fixing legumes with grain crops.
- The clearing and subsequent cropping of land leads to changes in soil hydrology, especially an increase in evaporation and most likely a substantial increase in deep drainage. Combined with changes in nutrient cycling in the topsoils an enrichment of available K and Mg may occur, but could not be fully substantiated.

To investigate the nutritional status of the crops, pearl millet leaves were sampled from plants growing at the soil sampling sites. The nutrient contents of the analysed leaf tissues were compared to values derived from the literature for plants growing in soils of differing nutritional status (Gascho et al.1995, Bationo et al. 1993, Krogh 1997, van Duivenbooden et al. 1996). It can be assumed that nitrogen is not deficient, whereas phosphorus seems to be deficient, even though pearl millet is often a host for Vesicular-Arbuscular Mycorrhiza (VAM) fungi, which generally enhance phosphorus uptake. Potassium contents in the leaves collected from the plants growing in the study area were generally in the medium range, while magnesium and calcium contents were mostly low. Magnesium contents especially were so low that symptoms of deficiency are most likely present in the area. Generally, micronutrient concentrations in the leaves were found to be in the medium range. What was noticeable was the high concentration of copper and zinc in the leaves analysed from the study area, which may indicate a symbiosis with VAM fungi.

In summary, the overall fertility of the soils in the region is generally low, and due to the dune/inter-dune differences, the nutritional status of the soils is highly variable. On the areas, which are currently cropped, the concentration of exchangeable cations is in a medium range while nitrogen and especially phosphorus are deficient. The very low organic carbon content, which is mostly below 0.5% is critical for agricultural purposes since this restricts the Cation Exchange Capacity (CEC) as well as the water retention potential in these sandy soils. Also the Fertility Capability Classification (FCC) developed by Sanchez et al. (2003) pointed out a high risk of nutrient leaching and the low nutrient reserve in most profiles due to the sandy substrate.

Microorganisms for sustainable landuse

Microorganisms are a vital and dominant component of the soil ecosystem as they significantly influence the cycling of nutrients and carbon by decomposing plant and animal residues. In natural ecosystems the availability of nitrogen often limits plant growth. It has an impact on the productivity and species composition of plant communities and on ecosystem processes at all scales and when in short supply the input of nitrogen fertiliser is usually required needed to grow crops.

A multifactorial study of microbial processes related to nitrogen cycling was carried out in the years 2007 and 2008, covering a gradient of different landuse intensities and major soil types of the region (Zul 2008, Mayer 2009). Multivariate analyses indicated that in the Kavango soils, the effects of landuse and soil type on soil alkalinity, pH and organic carbon content are accompanied by significant changes in bacterial biomass and nutrient cycling. Bacterial biomass and, in particular, the affinity of soil microorganisms towards cellulose residues (using the enzyme β-glucosidase as an indicator) was strongly correlated with high concentrations of exchangeable cations and low C/N ratios.

Five different (sub)phyla (*Actinobacteria*, *Acidobacteria*, *Alphaproteobacteria*, *Firmicutes* and *Chloroflexi*) were found to dominate the bacterial communities in Kavango soils. Analysis of a large 16S rRNA gene clone library from a dark pristine inter-dune eutric arenosol revealed an unexpectedly large bacterial diversity, which even surpassed the diversity known from soils from certain temperate regions of the world (Romann 2008). While little was known regarding the possible function of *Acidobacteria* in the soil environment, laboratory isolates of these bacteria were obtained and subsequent work of the microbial ecologists' team revealed that these bacteria are especially well adapted to degrade polymeric soil organic matter by the use of a large arsenal of hydrolytic exoenzymes (Koch et al. 2008). These results suggested that soil bacteria in Kavango soils may play a decisive role in the regeneration of nutrient, especially inorganic nitrogen compounds.

Indeed, stable carbon isotope ($\delta^{13}C$) signatures revealed that the conversion of pristine dark inter-dune soils into cultivated fields is accompanied by a marked transformation of the low molecular weight fraction (fulvic acids) of organic matter. Based on the $\delta^{13}C$ signatures of this dynamic fraction, it was concluded that this fraction is mainly derived from grasses rather than herbs, shrubs or trees unlike the other, more stable high molecular weight fractions (Mayer 2009). Follow-up laboratory measurements of the nutrient regeneration potential of the different soils yielded complementary results, since only the pristine plots showed a net liberation of nitrate by microbial activity. In contrast, no net regeneration of inorganic nitrogen was observed in cultivated fields and fallow lands.

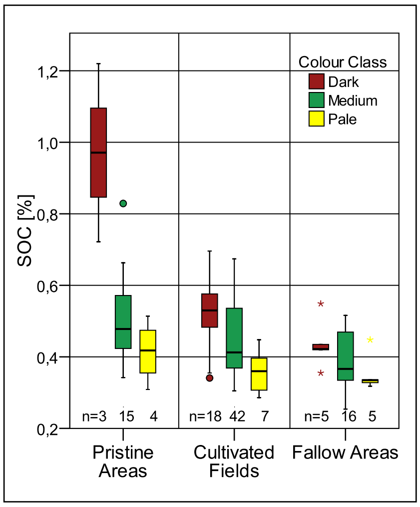

Fig. 10: Organic carbon in the topsoil of dark and loamy, normal inter-dune, and pale sandy sites under three different landuse types.

Based on the results of this first comprehensive soil microbial ecology study in the region, it can be concluded that landuse in the Kavango Region exerts pronounced effects on the cycling of microbial nitrogen thereby causing the well documented decrease in soil fertility. The rapid depletion of nutrients can be attributed to a rapid decline of the low molecular weight pool of soil organic matter by the activity of soil microorganisms. This low molecular weight organic matter fraction apparently serves as a source especially of fixed inorganic nitrogen but cannot get sufficiently replenished during extensive cultivation or even during early fallow stages. In contrast to current farming practices, a recycling of organic litter would therefore be expected to ameliorate soil nutrient reservoirs, the nutrient adsorption capacity, as well as the microbiological activity of soils in the Kavango Region.

Some microorganisms have the potential to restore soil systems, which have been exhausted by human uses. They increase nutrient input via the fixation of atmospheric nitrogen through the enzymatic reduction of N_2 to ammonia. This biological reaction, which counterbalances the loss of N from soils or ecosystems by denitrification or wash out could play a particularly important role in the nutrient-poor Kavango soils. Therefore biological nitrogen fixation was one focus of the microbiological research to counterbalance nitrogen losses and to improve soil fertility for a more sustainable landuse.

Generally, regulatory mechanisms for N_2-fixation are not well understood in terrestrial ecosystems (Vitousek et al. 2002) especially in non-legume systems. In certain grass systems, activity of these bacteria and thus contribution to a more sustainable soil use is probably higher than expected (Hurek et al. 2002). Interestingly, the most active, nitrogen-contributing bacteria may reside in the plant in an “unculturable” state but can be detected by their genes for the key enzyme for nitrogen fixation, nitrogenase (Hurek et al. 2002, Hurek & Reinhold-Hurek 2005). Whereas the retrieval of nitrogenase gene (*nifH*) DNA or other genes from the natural environment only shows the mere presence of nitrogenase genes or the diversity of diazotrophs or other groups of bacteria, estimation of processes in the environment are required to assess functional diversity or activity. Studies on the expression of nitrogenase genes (mRNA) carried out by reverse-transcription-polymerase chain reaction (RT-PCR) (Hurek et al. 2002) allow the evaluation of the actual activity of microbes in the natural environment and the identification of the primarily active diazotrophic bacteria.

A wild species of rice, *Oryza longistaminata*, was observed to show abundant vegetative growth at several sites along the river bank of the Okavango River despite the nutrient poor sand in the area. Although there is almost no traditional knowledge about this plant and its utilisation, our observations suggest that it might be a valuable resource as cattle fodder. Detailed culture-independent studies on the nitrogen-fixing bacteria associated with this species demonstrated that nitrogenase genes were actively expressed in association with its roots. However, the bacterial consortium was rather diverse and unlike most other nitrogen-fixing nodule symbioses (Demba-Diallo et al. 2008). The mRNA levels were resistant to nitrogen input at low levels corresponding to atmospheric N-depositions in industrial areas, suggesting that nitrogen fixation was not affected by small anthropogenic disturbances (Demba-Diallo et al. 2008). Additionally, nitrogenase gene expression was also detected in roots of sugar cane (Burbano et al. 2010), a plant that is locally grown (see Table 1) at small scale in the Kavango Region but used as an energy crop at large scale in Brazil. Our results are still tentative but suggest that root-associated nitrogen fixation may contribute to the sustainable productivity of the grass species mentioned above.

Millet, maize, and sorghum are grown with low input of nutrients resulting in very low yields. Microorganisms may contribute to improving yields by plant-growth promotion, biocontrol of pathogens, and by increasing of plant tolerance to stress. Therefore, endophytic bacteria residing in roots of these crops were isolated and characterised with respect to their taxonomic affiliation and putative plant-growth-promoting characteristics. A diverse range of partially novel bacteria was detected, which contains promising candidates for application in sustainable agricultural management. To allow application of these resources in Namibia, a Namibian Type Culture Collection of Microorganisms was established with our help at the University of Namibia.

1.6 Human aspects of cultivation within the farming system

Outline of this sub-section

Now we will turn attention to the anthropogenic subsistence oriented farming systems, which currently dominate the rural Kavango Region. These systems are generally based on a broad variety of activities like crop and livestock production, off-farm employment and usages of natural resources. Fig. 11 shows important elements of the prevailing farming system in the Kavango Region with their deliveries, and their major linkages.

Within this farming system crop cultivation is the dominant food production strategy. The contribution of livestock to the diet (meat, milk etc.) is very small (Falk 2008, Pröpper 2009a) even though livestock has an important saving and insurance function in the livelihoods of interviewed farmers (Falk 2008). In addition, cattle—mainly oxen—are the main draught power (DAP) and hence are a central production factor in cropping. Only about 50% of households in the research sample of 120 households possess cattle. All components contribute to a varying degree to the cash income pool of the household. In addition, remittances and pensions are the primary and relevant non-farming related cash income sources.

Physical and financial capital

Farming activities are constrained by capital availability. A households’ physical capital is often limited and farmers produce a large proportion of items of their mobile physical capital from natural resources—with manual labour input and very little financial capital. An indicator of poverty derived from the census data suggests that on average three persons share one sleeping facility. In 20% of the households people sleep together on one reed mat or blanket, which is lying on the ground, while 33% of households use traditional beds made from tree branches and are bolstered with reeds and grass and 36% of households use poor quality frame beds and mattresses from urban shops.

Productive capital—that is especially relevant for agriculture—comprises axes, hoes, sledges, oxen, seeds, sacks, drums, buckets, shovels and rakes. No household in the complete research sample possessed and/or used a tractor. Numbers for the whole region indicate that tractors are only used by 7% of rural Kavango households (Mendelsohn & el Obeid 2003: 92, 94), of which most households rent the tractor and driver. 90% of the people in our sample were ploughing their fields exclusively with ox-drawn steel ploughs. Despite the fact that cattle have a very high cultural value only about half of all households own cattle and a plough. A larger fraction of households in the whole sample have to rent ploughing as a service that they will have to pay or work for.

The possibilities for rural households to generate **financial capital** are limited and are concentrated on off-farm labour, remittances, pensions and credits. A few forms of casual labour, such as herding, work-gatherings and collective domestic help, exist within the villages but they are almost exclusively compensated in kind. The remoteness of rural villages and poor education of most farmers hamper their integration into a formal labour market. There is, however, a long tradition of labour migration to the mines and fruit orchards in the remote south where an unqualified and unskilled workforce is needed (see for example Likuwa 2001).

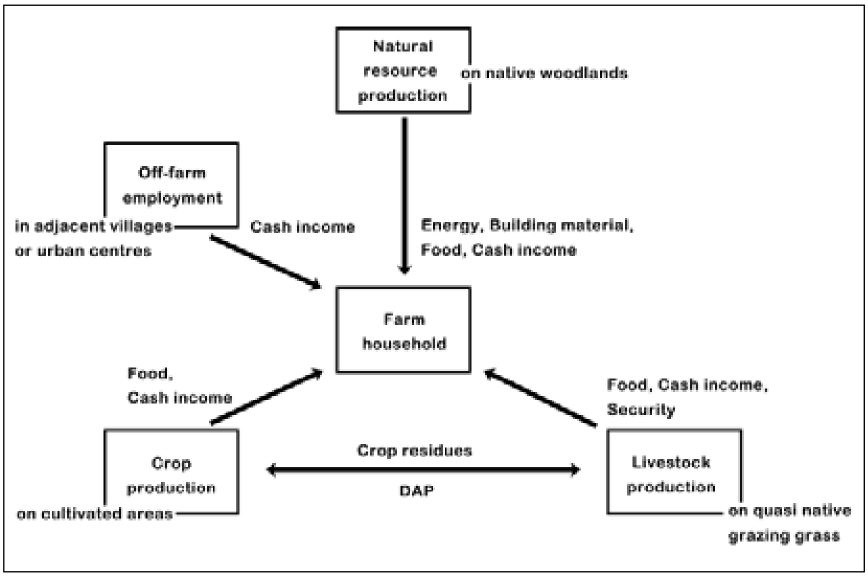

Fig. 11: Major elements of the prevailing livelihood system in the Kavango Region. Modified from Matsaert et al. (1998: 1).

Because remittances are an irregular contribution to household budgets they have to be considered of peripheral importance for this study. Even though informants regularly emphasised the relative importance of remittances for the household economy (cf. Falk 2007: 70f.), less than one third (32%) of census households have an affiliated labour migrant that might send or bring goods or cash. State pensions granted to all Namibian citizens above the age of 60 are another additional source of financial capital. However, only 13% of all study-households profit from state pension income, a fact, which can be partly explained by the high mortality and partly by the portion of migrants from Angola who do not have proper documents of Namibian citizenship. Only two households dispose of two pensions equalling a monthly income of approximately €60. People regularly claim though that state pensions bring an enormous relief to households' budgets.

The relatively high transaction costs to store financial capital are compensated by investing surplus money into livestock, which functions as an alternative medium of capital accumulation, bank account and insurance against misfortunes and food shortages (cf. Falk 2007: 70f.). In addition to their role in providing draught power cattle also function as a traditional currency, e.g. in cases of court fines. The absence of adapted capital markets therefore increases pressure on natural resources and inhibits savings being used productively for capital investments as a basis for development.

The lack of financial capital is a constant problem for rural farmers. A survey by the Social Sciences Division of the University of Namibia from 1995 stated that, despite a high demand, very few farmers have access to formal bank loans (SSD 1996). According to the study farmers countered these restrictions by accepting interest-free, informal short-term loans by cash-earners and shop-owners. The study reports, however, that only 20% of these credits were flowing back into agriculture (SSD 1996: iv). Interview partners in our study repeatedly reported that attempts to secure formal loans was a risky strategy since cattle were often used as collateral and could be easily forfeited if climate or other conditions deteriorated during the course of the agricultural season.

Field sizes and productivity analyses

On average households own 1–2 fields depending on the household size (mean: 1.46 fields per household, $N = 107$). Average sizes of land holdings differ considerably among and within publications (see Keyler 1996, Phororo 2001, Werner 2008). In the literature land holding sizes range between 1.7 ha and 7 ha (Jones & Cownie 2001: 31, Ministry of Agriculture Water and Rural Development 2003: 34, Mutwamwezi & Matsaert 1998). Field sizes assessed within our project lie above these calculations. 22 fields were measured using GPS Data in 2006. For this survey the actual territory in use was measured—neglecting the wider borders of fields from former years. Additionally for the calculation of productivity the main fields of nine households representing social stratification were measured and cross-checked using aerial photographs. In most cases the coordinates that were taken on the ground roughly matched the field borders visible on the photographs. A 2008 assessment of existing data using a metre-measurement of field borders was used to confirm existing data for these fields. One field within the survey was considered as being unusually large at 32.5 ha, while two other fields were slightly less than 20 ha. This latter size that was perceived to be large but not unusual. Accumulating values for 22 fields resulted in an average field size of 9.82 ha (median 7.2, SD 8.86). The assessment of field sizes remains a challenging task since survey data can certainly not rely on farmers estimates. Moreover, farmers change the size of their fields frequently due to situational factors (e.g. soil properties and yields,

Table 2: Comparison of various crop-related statistics from different studies carried out in northern Namibia over the last two decades

Researcher and study period	Pröpper (2003–2005)	Hecht (2005)	Keyler (1992/1993)	Mendelsohn & el Obeid (2003)
PLOT SIZE				
Average field size (ha)	9.82	4.20	3.00	4.50
LABOUR INPUTS				
Average number of HH labourers	3.48	3.87	3.40	
Average labour input per HH all crop production (man days)	256.56	125.84	147.00	
Average labour input per HH all crop production (HH work days)	73.72	32.52	43.24	130.00
Man days per ha all crop production	26.13	29.96	14.40	
Average labour input per HH (work days) millet only			76.00	
Average labour input per HH (man days) millet only			258.40	
Average HH millet-input days yearly			76.00	
YIELD				
Net yields yearly all millet varieties (kg), mixed cropping	630.83	910.81	678.00	450.00
Net yields yearly all millet varieties (kg), pure cropping		1386.00		
Net yields yearly maize (kg), mixed cropping	102.29			
Total yearly net yield two main crops (kg)	733.12			
Estimated total net yield all crops	933.00			
LABOUR PRODUCTIVITY				
Labour productivity millet mixed cropping (kg/man day)	2.46	7.24	4.61	
Labour productivity millet mixed cropping (kg/HH work day)	8.56	28.01	15.68	3.46
Labour productivity all crops mixed cropping (kg/man day)	3.64			
Labour productivity all crops mixed cropping (kg/HH work day)	12.66			
CAPITAL PRODUCTIVITY				
Land-productivity millet mixed cropping (kg/ha)	64.24	216.86	226.00	100.00
Land-productivity all crops mixed cropping (kg/ha)	95.01			

available labour, age, diseases, available seeds, diversification through job offers/grass cutting, time of available ploughing, weather influences, etc.). This leads to an on-the-ground situation of partly polygonal core fields that are surrounded by a frayed edge of expansions and/or fallow lands. Only regular updates of field-size measurements on the ground, flanked by remote sensing data, could give a precise picture of the extent of changes in cultivated land. Nevertheless, comparing the averages assessed in the nineties with recent study data we consider it safe to conclude that average field sizes are growing (Table 2).

Yields in region-specific publications are rarely mentioned and if they are then they vary considerably as well. Yield levels per ha mentioned in different publications range from 60 kg to 625 kg (Jones & Cownie 2001: 37, Mutwamwezi & Matsaert 1998: 10, Yaron et al. 1992: 49). A more plausible span comparing farmer estimates of yield levels to data obtained from crop cuttings is provided by Jones & Cownie (2001: 32) resulting in values, which range from 100 kg/ha to 300 kg/ha. Table 2 compares the data for crop productivity from four different approaches.

Comparing these productivity data shows some significant differences. According to data from the study area (Pröpper 2009a: 196ff.) land-productivity is actually far lower than most other figures that can be found in the literature. Mendelsohn & el Obeid (2003: 94ff.) calculated a slightly higher land productivity with smaller field sizes, very high labour input and smaller yields. Such calculations of productivity based on averages have the disadvantage that they do not represent the strong stratification that exists between households (cf. Mendelsohn & el Obeid 2003: 98). As has been shown above the wealth distribution amongst Kavango households is very high and consequently different households have different capital available to face stress and shocks such as unpredictable rainfall, infestation by pest insects and birds, damages caused by livestock entering fields, or disease and illness of the productive workforce. Households choose diverse strategies depending on the quality and quantity of labour, land (e.g. patchiness of soil fertility, Wisch 2008: 44), seeds, and physical capital available as well as individual preferences. Convictions about agricultural performance being influenced by witchcraft play an important role as well. These factors aggravate the valid assessment of agricultural productivity. Average yields of 95 kg/ha (see Table 2) as calculated by Pröpper (2009a: 196ff.) are clearly insufficient to sustain food security of households and suggest that a key household

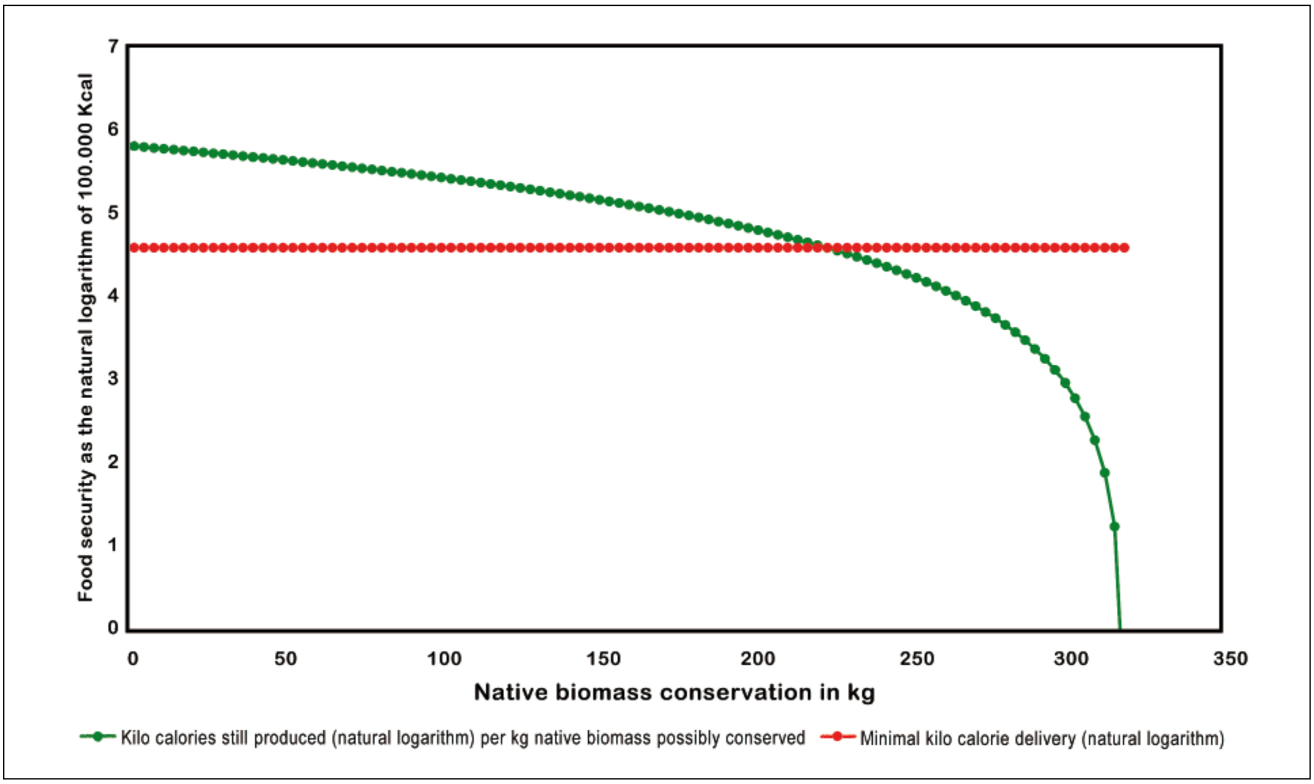

Fig. 12: Trade-off between food security and native biomass conservation under the status quo (baseline scenario). Source: Hecht (2009, based on MAPOM).

strategy to counter shortages is the expansion of fields where sufficient labour input is available.

The assumption that a larger field will bring more output though turns out to be simplistic. Equally problematic is the assumption that more labour-input will generate a higher productivity. Fast and effective (thorough) clearing, ploughing and weeding certainly will bring some limited improvement. But, given the constraints of soils and low capital-input an increase of manual labour will have only limited returns. The employment of tractors—strongly linked to capital availability—might result in an increase. But, in relation to given soil and rainfall parameters and other impacts, field size has a much stronger effect. Additionally the lack of input of capital could be improved. However, upon interviewing 25 informants about how they would like to increase productivity only 12% preferred increasing the size of their fields while 24% opted for the application of machines, another 20% opted for the fertilisation of soils, while 16% perceived the application of manure as a possibility.

Assessing trade-offs between food security and biomass preservation

Because of the high degree of variation within the farming system of the Kavango Region a model (MAPOM) was developed to assess the influence of different combinations of input and output variables on the productivity of the system. In terms of crop production this resulted for instance in a set of 32 millet production activities for which demand-driven (labour inputs/techniques) and output-driven (yield levels) variables differed. Under the status quo (without changes of policy conditions, in the following named baseline scenario), the results of MAPOM show that in terms of crop production households are attracted by a) labour saving technologies for weeding and ploughing, and b) millet production activities, which promise high yield levels. Moreover, they continuously supplement domestic millet production by purchases and store outputs in years of peak production levels to balance insufficient production levels in periods, which follow. Also, households rarely sell any crops and meet minimal kilo calorie requirements in each year. In terms of livestock production it can be summarised that households are only engaged in cattle production to a minor degree and base their production on the traditional livestock system. They do not take part in “improved” cattle rearing activities. In general, land and labour endowments are a constraint for cattle production.

As indicated above, the modelling exercise showed that crop production is the predominant farming activity, which generates food, in terms of kilo calories. On average households generate 31,469,360 kilo calories from their crops each year. Simultaneously, crop production destroys significant amounts of native biomass. For instance the production of 1,000 kcal is destroying 3.14 kg of native biomass (averaged over the entire planning horizon of 30 years and aggregated for female and male headed households). Hence, a trade-off between food security and native biomass conservation can be assumed. This relationship can be illustrated by the trade-off curve shown in Fig. 12.

Assuming that the produced kilo calories (presented in Fig. 12 as the natural

Table 3: Perceived reasons for soil fatigue (*N* = 25, several answers possible)

	N	%
Ploughing	11	44
Don't know	7	28
Grasses (mainly Esusu and Kandjata)	3	12
Lack of manure	3	12
Poor rain	2	8
In rainy times water stands	1	4
Planting same plant every year	1	4
No use of fertilizer	1	4

logarithm [*ln*] in 100,000 kcal) are generated without any native biomass conservation delivers the intersection with the y-axis. Reducing this level of kilo calories produced continuously by 3.14 kg delivers the intersection with the x-axis. At this point kilo calories obtained by crop production (food security) equal zero. The straight (red) line illustrates the lower limit of kilo calories that have to be produced each year to meet a minimal acceptable nutrition level. At a maximum, 220 kg native biomass can be potentially conserved (intersection of straight line and curve). Imposing native biomass conservation to go beyond this line would threaten food security to a major degree. Obviously the potential to conserve native biomass will decline if less native biomass is destroyed and vice versa. In a scenario run we will investigate if this potential could be reduced by a designed fee system for landuse.

Cultural determinants of cropping decisions

The whole crop economy in the communal areas of the Northeast of Namibia has historically grown and is embedded within tradition and cultural knowledge and values. In earlier times of lower population density people were able to utilise relatively abundant natural resources and cropping was complemented by hunting and the collecting of natural resources (Mendelsohn & el Obeid 2003: 37). The collecting of fruits and wild vegetables is still being practised although it appears to be diminishing (Pröpper 2009a: 152). With the increase in population along the Kavango River and the decrease of available fertile soils that triggered the migration to the hinterland farmers have had to employ new kinds of technological and practical knowledge and capital investment. This has been accompanied and stewarded over the years by extension services of differing contact intensity, which has introduced ploughing as the main method of agriculture.

Against this background anthropological assessment of traditional farming knowledge and practices has tried to understand the current consensus on certain items and to identify where mutual knowledge disparities between local and scientific knowledge lay. It has been shown elsewhere in great detail that the perceptions and environmental knowledge of the farmers of the Kavango Region are clustered around utilitarian criteria meaning that farmers know best what they use most (Pröpper 2009a: 125ff.). In comparison to some botanical domains like healing plants, wild fruits or poisonous plants, where the average informants' share of known plants from the whole pool of named plants was rather low, crop plants, which can be used for consumption and marketing achieved a high consensus and salience (Pröpper 2009a: 153). Beyond mere taxonomic knowledge around the plants that have been listed in Table 1 a body of values, rules and practices of preparing soils, planting and growing plants is culturally transferred and known. It seems though that utilitarian economic cultural knowledge is not informed by knowledge about the ecological values of certain associations like *Acacia fleckii* bushlands. Analysing the salience of *Acacia fleckii* from freelists with a salience analysis it was found that the species has a low cultural salience and is only known for one type of use—roof constructions (Pröpper 2009a: 151). This means that in the case of this especially endangered species utilitarianism does not function as a protective or preservative mechanism.

Likewise farmers seem to lack explanatory models, e.g. for the lack of soil fertility. 72% of interviewees (*N* = 25) described their actual cropping soils to be sandy, while one third or less declared their fields or parts of their fields as having been allocated on slightly darker and thus slightly more fertile soils. Different properties are ascribed to different soil colours and almost all farmers (92%) agreed that 'Ndombe' is the most preferred soil because it best holds the water.

Furthermore, the results of a farming system survey of 25 farmers held in 2006 showed that their explanations for soil fatigue were diverse (Table 3). While the majority held ploughing accountable for the decrease in soil fertility a range of other factors such as as the absence of fertilisers, crop succession or water availability were also perceived by others as the most important reasons for soil fatigue.

Knowledge on sustainable intensification as a short term strategy to reduce pressure on biodiversity—ideally transferred through extension services—has been found to be deficient as well (compare Werner 2008). In answer to the question of what they would do 'when the soil of a field is getting old', seven farmers (28%) replied that they would do nothing but keep on using the field as long as possible. The problem of decreasing soil quality is counteracted with few strategies, amongst which fallow, described as "letting fields rest", is a dominant one that was mentioned by six farmers (24%). Nevertheless, while some farmers don't react to the problem, others react by abandoning their fields and/or expanding (20%). Some fallow fields are then replanted after some years. Only two farmers mentioned the option of using cattle manure, though this practice has never been observed during research. The ploughing in of crop residue is not a dominant cultural practice since crop residue is eaten by cattle, is used for construction purposes (e.g. fences) and is often piled up and burned as well.

Another area in which knowledge and applications vary significantly between individuals is in the area of technological preferences and cropping styles. The chosen mixture, proportion and distribution of crops that farmers apply on their fields are not unified, and there are few shared rules in this regard. It is common cultural knowledge though that the intercropping with legumes improves the soil fertility. Apart from this aspect each farmer decides on his cropping style and crop mixture according to the availability of sufficient land, seeds and personal preferences. During the farming survey farmers were interviewed on their strategies and additionally fields were observed and mapped according to crops and soils. The results show several styles that differ from separating crops on different field to mixing crops unsystematically (Pröpper 2009a: 188).

Cultural rules about the season, the availability of labour, draught power and the individual status of clearing/cleaning of fields determine the decision about the convenient point in time to start ploughing. Ploughing is immediately followed by sowing, a practise that is done by the women again following cultural rules.

Epungu (Maize) seeds are bigger than Mahangu seeds and have to be planted deeper to grow well. Besides that Epungu grows faster. Epungu and nuts of the species *Vigna subterranea* (Nongomene) will be planted by following the plough along the ploughing line so the seeds will be covered by the sand being overturned from the next row. That means that only every second row is planted, leaving more space for the Epungu to grow. Mahangu seeds are small and cannot be planted too deep. They will be planted at right angles to the ploughing direction by dropping the seed and burying it with the feet. Other seeds e.g. for sugar-cane, Nomusipo or Makunde beans, are just thrown out from a basket. A crucial point here is the fact that the ploughing/sowing point and the onset of the rainy season can be apart, hence the seeds can lie for longer periods in the dry top-soils heated by the sun.

Another observation to note is the social embeddedness of all environmental decisions taken by subsistence farmers. It has been found that environmental decisions are strongly influenced by social ties and that kinship ties play a major role. Such structures of social organisation reflect a set of institutional rules, which influence individual action. People are first and foremost members of family dominated households, which are self-reliant economic units. Especially female-headed households often lack male labour and are economically vulnerable. Most female and male headed households can be described as nodes in larger translocal (rural-urban, rural-riverside) kinship networks, which cooperate by, for example, exchanging goods and taking care of children's school education. Within villages, households and household members have a long history of known social interaction. Against a background of widespread poverty, interaction between households involves mainly short-term balanced reciprocity and ostentatious small scale giving. Deeper exchange relations are preferentially established with kin, followed by friends, leaders, and office bearers. These kinship-based networks are the nuclei of collective action and the main social capital of people. These findings indicate that the involvement in traditional social networks also functions as a mechanism of rule enforcement and collective action, which are essential prerequisites for environmental protection and sustainable resource-related behaviour. The collective, and its rules of kinship-based cooperation and reciprocity, limit the choice of actions but also make up an essential part of actors' social capital, a crucial insurance. Any information on biodiversity preservation is filtered through social networks and evaluated against a background of social and cultural utility that involves e.g. inner-family and/or inner-village power hierarchies. The involvement and belongingness in social collectives has been found to have a high cultural value that resists and competes with needs for individualised need-satisfaction and consumption.

The traditional matrilineal kinship system is widely intact, though some processes of transformation can be observed. In use are, at least in the rural villages, firstly clan and lineage identities and relevant rules of behaviour such as lineage exogamy, and secondly a classificatory kinship terminology, which functions as a cultural script for relevant rules towards different groups of relatives (matrilineal, patrilateral, affinal). Besides this, migration and settlement patterns seem to develop strongly along relationship lines.

Against a background of economic vulnerability and scarcity, households struggle with a range of domestic problems. Little access to markets and financial capital, increased alcoholism, unequal gendered labour division, domestic violence and divorces are visible. In addition, teenage pregnancies and children from multiple fathers increase young women's vulnerability. HIV and AIDS are being perceived as threats but so far prevalence in the rural communities of the sample is perceived as being low.

People are economically deeply rooted in local biodiversity, but equally they are socially rooted in a system of kinship reciprocity and cooperation. These rules and norms govern not only the way produced resources are being distributed but also the way knowledge and awareness are being mediated, evaluated and eventually enforced at the local level. A closer look at social structures has shown that 'communities' and approaches of Community Based Natural Resource Management cannot be thought of without detailed knowledge of the traditional rules and rights of social interaction that form people's scripts for action.

Actors' cosmological models have been found to strongly influence environmental perceptions and economic actions. An aetiological model of envy-based witchcraft has been found to be equally salient. Beliefs in the consequences of social interaction with supernatural entities have been found to clearly influence economic and natural-resource related decisions of how to mitigate risks by reserving crop yields (Pröpper 2009a). In all these cases that can only be briefly outlined here it has become apparent that farming decisions do not exclusively follow models of economic utility but are deeply embedded into cultural background.

Impacts of grazing on communal rangelands in the Mutompo region

As we have outlined before, livestock production has a stabilising function in the livelihoods of Kavango farmers as draught power, cultural capital, and saving and insurance instruments. Livestock production hardly contributes to the continuous food supply of households and is not produced for commercial marketing. Considering the competing interests of biodiversity maintenance and livelihoods one has to bear in mind, however, that livestock farming does not require such a fundamental transformation of habitat as cultivation practices. It remains debatable if the potential exists to increase the efficiency of livestock production in order to increase the perceived value of forest pastures by contrast with cleared fields. At least from a theoretical perspective, increasing the value of forests might produce powerful incentives against deforestation.

Livestock numbers in the Kavango Region have increased since 1996, from a stocking density of 5 kg ha^{-1} to around 11 kg ha^{-1} in 2000, while the stocking density in Mutompo was at 15 kg ha^{-1} in 2001 (Schneiderat, in prep.) and at around 19 kg ha^{-1} for the ethnographic census area (Pröpper 2009a: 207). However, heavy grazing by livestock is restricted to the area around the water point and around the huts within the settlement and overall stocking has not yet reached critical carrying capacity limits. Small cattle paths lead the livestock from the central water point into grazing areas in different directions, which are preferred to the dry forest areas. Within the first kilometre from the central water point in Mutompo, the impacts of landuse are detectable, in most of the tested parameters for grass, trees, and bushes (Schneiderat, in prep.). The area of the so-called sacrifice zone is the area in direct proximity around the water place (~150 m distance to the water point). Because of the high impact of animal trampling, this zone is nearly without vegetation and only grazing-resistant annual grasses are able to grow and persist here. The human induced impact zone around the village has a radius of approximately one kilometre. Beyond this zone mostly a dry forest area starts to become noticeable. In these forests, the grasses and ground vegetation as well as the young bushes and trees compete with higher trees for light, soil water and nutrients, each using different strategies (e.g. the development of very deep or very flat but extended root systems). The inter- and intra-species competition within dry forests occurs concurrently with the impacts of grazing by livestock (Schneiderat, in prep.).

In the Mutompo area, where the rangeland is not overstocked or overused, the signs of grazing and trampling caused by livestock were regionally limited, and exist at an acceptable level. A high potential for all livestock species was found for Mutompo, despite the bush fires, and also despite the relatively low rainfall, which occurred in the 2002/2003 season (Schneiderat, in prep.). However, the poor soil fertility leads to a deficit of phosphorus and maybe of calcium, and probably also leads to a deficit of even more essential macro- and microelements for animals. A deficit of protein is expected more likely to occur, rather than a deficit of energy, because the quality of grasses, especially their protein content, decreases quickly to a low level after the seed has ripened (Schneiderat, in prep.). Probably, a more effective use of the browsing recourse can compensate the protein deficit. Additionally, the low productivity of cattle in this community can be explained by a mineral deficit on the one hand, which can cause infertility and a disturbance of growth. On the other hand, cows stay within herds for a relatively long period, and thus get quite old, which can also cause lower calving rates (Schneiderat, in prep.). The low performance may also be associated with the fact that, in this mixed farming system, livestock is only of secondary importance, compared to the main focus on crops.

1.7 The role of statutory and customary law in governing the cultivation of land

Background

The Namibian Constitution declares that “land, water and natural resources below and above the surface of the land (...) belong to the State if they are not otherwise lawfully owned” (Republic of Namibia 1990). More specifically Kavango land is vested in the state, which is obliged to administer the land in trust for the benefit of traditional Kavango community (Republic of Namibia 2002, Hinz 1995, Falk 2008). The ownership status is, however, not as clear as it looks at first glance (Blackie 2000). For instance, the constitution stipulates as well that customary law in force on the date of Independence shall remain valid to the extent to which it does not conflict with any statutory law (Republic of Namibia 1990). The legal question arises as to whether Kavango land is in fact otherwise owned under recognised customary law. Traditional authorities, having by law the duty to ascertain customary law (Republic of Namibia 2000), emphasised in interviews that the natural resources on Kavango land are owned by the community. Kavango’s traditional authority system is a three level authority headed by the ‘hompa’, a traditional king and the leading legislative, judicative, and executive organ. In Mapaure’s study on tree ownership, 52% of the respondents (*N* = 37) highlighted that the whole community owns the trees and only 19% mentioned the state as the owner (Mapaure 2008). This discussion shows that contradictions exist both in the law books as well as in the perception of stakeholders. Unclear property rights reduce the sense of ownership for natural resources and incentives for a long term sustainable resource management.

In particular in an environment, which lacks institutional clarity, farmers tend to rely on the traditional authority system and customary law that is culturally close to them, since the legal culture is deeply interwoven into other aspects of Kavango life. Traditional authorities play a central role in resource protection and the dissemination of information and awareness. It must be seen in this context that despite the lack of tenure clarity, the majority (77%, *N* = 29) of Falk’s (2008) respondents expressed a strong feeling of security of their use rights.

Looking more specifically at the allocation and registration of land for cultivation purposes one first has to acknowledge that both statutory and customary property rights on fields are largely grouped together. Under both types of law the field “owner” has the right to use, to exclude, to obtain benefits and to receive compensation for damages. Only the right to transfer is restricted as no freehold ownership of communal land is permitted. However, the Communal Land Reform Act of 2002 makes provision for the allocation of individual inheritable and transferable land rights (Falk 2008, Republic of Namibia 2002).

The establishment of a field is therefore a form of privatisation of communal land.

Under customary law only residents of a settlement are allowed to clear forest for making fields. In order to become a resident one has to follow a complex procedure under the traditional legal system, which is a three level authority headed by the hompa, a traditional king and the leading legislative, judicial, and executive organ. Applicants for residency need a letter of personal record from the place where they lived before. The letter explains why the person left or had to leave the place. The local traditional authority of the preferred residency will grant a piece of land only subject to the agreement of the residents (Hinz 1995, Mendelsohn & el Obeid 2003, Falk 2008). This veto right of local residents is a very important control mechanism as it ensures that benefits from the residents' investments cannot be appropriated by strangers. The residents also know best whether the natural resources can sustain another household and whether a new person will fit into the settlement (Falk 2008). Once recognised as resident the local traditional authorities will allocate a piece of land to the person for establishing a field. Opportunity costs are considered in this allocation by, for example, avoiding the making of fields in prime pasture areas.

Since independence, the government of Namibia has been faced with the challenge of formulating and transforming and reform land reform policies for the reformation of both communal and commercial agricultural land. It must be seen in this context that the Communal Land Reform Act of 2002 formalises the allocation of customary farming rights on land for cultivation (Republic of Namibia 2002). Farming units for cultivation of a size not exceeding 20 ha (Republic of Namibia 2003) may be allocated by traditional authorities to individuals for exclusive use (Republic of Namibia 2002). The registration of larger fields requires the approval of the Ministry (Republic of Namibia 2003). In order to receive a legally effective customary farming right, the allocation must be ratified by the land board. Any right, which has not been ratified reverts back to the state and is expropriated from the holder (Republic of Namibia 2002, LAC 2003). In addition, "if a board ratifies the allocation of a customary land right under section 24(4) (a), it must cause such right to be registered in the prescribed register, in the name of the person to whom it was allocated and issue to that person a certificate of registration" (Republic of Namibia 2002). Since the Communal Land Reform Act came into force, the registration process has begun in all communal land areas, except but the Kavango Region. The Kavango communities are opposed to the registration of customary land rights. The bone of contention is that such registration is against their customary farming and land management practices. In a survey by Namwoonde (2009) in which 30 respondents were asked whether the rule of registering fields was in conflict with their customary practice, 63% answered yes, 20% no and 17% were not sure.

In a meeting held on the 4th June 2007 among the five traditional authorities of Kavango and the Deputy Minister of Lands and Resettlement, the authorities submitted a petition, wherein they stated the reasons for refusal to register, which included, inter alia, ecological and socio-political reasons. They warned that the new formal registration procedures favoured wealthier landusers at the cost of the poor. The conflicts between customary and statutory law in combination with unclear ownership constellations increases the risk of powerful players taking advantage of the situation and expropriating small-scale farmers. Formally it is possible under current legislation that an outsider may register an official land right for a piece of land, which is in use by a local farmer who objected for whatever reasons to register his land.

The word of traditional authorities has to be taken seriously as the farmer community perceives traditional authorities to be the main decision makers on natural resource management issues. Fig. 13 shows the result of assessing contact relationships in cases of detrimental resource uses between all household heads in the village with the method of a complete social network analysis. In the figure men are depicted by gold and women by red globes and the size of the globes corresponds to the degree of centrality, the amount and reciprocity of relations (depicted by the arrows) that a person has. This analysis of resource related relationships shows that the traditional authority, the headwoman, has a high degree of centrality, meaning that her position in social exchange relationships like support, communication, knowledge transfer is especially strong. Farmers fear that the reform would interfere with their resource management powers. Considering the low capacity of government organisations to monitor and enforce natural resource use regulations one should be aware that the role traditional authorities currently play in the governance of land related issues can not easily be replaced. This includes specifically also conflict resolution mechanisms.

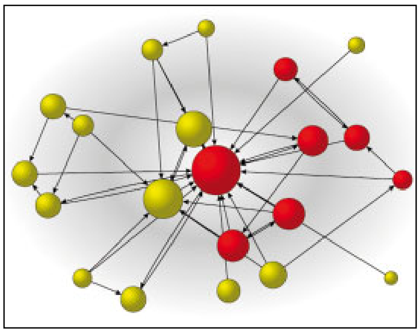

Fig. 13: Complete social network analysis in Epingiro (*N* = 21): whom would you contact in cases of detrimental resource uses? For explanation see text. Source: Pröpper (2009a).

This example is symbolic for the mutual scepticism and distrust between the system of traditional authorities and the state. Statutory organisations for resource protection are often perceived as opponents, instead of partners. State organs of resource management and law enforcement are understaffed and under-equipped to ensure effective resource management and protection. Both, representatives of traditional and government organisations accuse each other of being corrupt and abusive in the process of land allocation. Under these conditions the potential of resource users and traditional authorities to provide institutional services is insufficiently capitalised. Statutory as well as customary agents should increase their efforts to a) promote ownership by clarifying the legal status, b) empower people through information, c) raise awareness about the value and limitations of natural resources, and d) support a stronger cooperative involvement of different stakeholders. In a constructive polycentric setup different stakeholders such as local resource users, traditional authorities and state law enforcement could establish a cooperative governance framework, making use of advantages and compensating for each other's shortcomings.

Testing for policy change: modelling an enforced fee system

Under these rather unclear landuse and property rights practices it is difficult to promote more sustainable management approaches. One possibility to support landuse practices, which are less demanding of native biomass would be to oblige households to pay for their landuse activities. In the research area this has already been initiated by the implementation of a permit system on the usage of natural resources. However, currently this system is only partly enforced. Therefore, one scenario of MAPOM assessed the impacts of a complete enforcement. In this scenario the simulated households are compelled to pay a fee for the exploitation of natural resources. One result of the baseline scenario of MAPOM was that both households did not take part in an "improved livestock production" activity that was connected with higher labour efforts and higher weaning rates. In this context Masters & Dalton (1998) discovered in Mali, for example, that a relatively low level of pasture tax per livestock unit would increase the attractiveness of more labour and capital intensive confinement systems over free grazing livestock management. Besides pasture taxes or cattle fees can be considered as a policy instrument for counteracting future threats of pastures becoming overgrazed. Bearing these findings and relationships in mind, the fee for the usage of natural resources was implemented together with a fee for the keeping of cattle and for the establishment of new cropping fields. Levels of all considered fees were partly related to a) the existing permit system for natural resource exploitation (Pröpper 2009a: 290) or b) the prevailing fee level for water (for details see Hecht 2009). In order to test if the designed fee system would have the power to counteract native biomass destruction this scenario additionally considered a 50% increase of total land endowments on the village scale.

Results of the scenario run show only minor changes in terms of optimal landuse strategies. Likewise, native biomass destruction per kilo calorie produced is only slightly increased whereas average kilo calorie deliveries of crop products decline slightly. This indicates that the trade-off curve, as exemplified in Fig. 12, obtains a lower starting point on the food security axis and is faced with a stronger decline per unit native biomass potentially conserved. However, the maximal level of conserving native biomass without threatening food security is equal to the level of the baseline scenario.

The complete enforcement of a designed fee system for cattle keeping, natural resource exploitation and field clearing coupled with higher land endowments exclusively involve minor changes on economically optimal farming strategies. Notably, the potential to conserve native biomass remains equal. However, after a more detailed analysis of the results it becomes obvious that there is a difference in adaptation strategies between the two considered household categories. For details on differentiated results see Hecht (2009).

1.8 Summarising results

The results of this interdisciplinary study show that there is an increasing anthropogenic impact on land that was previously hardly affected by people at all. The population pressure has grown in the region due to migration and ongoing high human fertility levels. The trunk road B8 and the rivers (mainly the Okavango River and its tributaries) are functioning as major axes of development. We recorded the expansion of agricultural landuse patterns especially in the slopes and transition zones between dune crests and inter-dune areas of the dune and inter-dune soil groups. The core research area of our study is located in an area of most rapid agricultural expansion. In 2000, 8.6% of the natural vegetation had been cleared in a strip 30 km wide in the north-west of B8.

Expanding crop production in Kavango has a clear impact on the destruction of native biomass, which affects various species associations but also the successional progress and grazing quality of the vegetation. The *Eragrostis rigidior-Acacia fleckii* bushlands and the *Bauhinia petersiana-Acacia fleckii* shrublands are especially affected since these are relatively easy to penetrate and clear compared, for example, to the near-impenetrable *Acacia luederitzii-Croton gratissimus* thickets. They also have a relative fertile soil, compared to the transitional soils of the *Bauhinia petersiana-Acacia fleckii* shrublands and the pure and nutritionally-poor sands prevailing as substrate in the *Pterocarpus angolensis-Guibortia coleosperma* woodland/thicket association. The maintenance of this habitat is of high priority as it a) bears a high risk of complete transformation into cropland, b) is very limited in its geographic extent, and c) has a high economic value as it harbours highly palatable grasses. Its conservation, however, will put other community types at risk as well, as it will become more difficult to find patches large enough to establish crop fields with ever-increasing demand for crop production.

Pressures on natural vegetation have also become intensified by frequent bush fires caused by human uses of fire. Beyond that, fire is closely related to cropping activities, as it is used for the initial clearing of agricultural land and for burning crop residues on fields. It is beyond question that human-induced fires, which get out of control, have a strong impact in Kavango though moderate frequent fires have to be perceived as important for the Kavango ecosystems.

The cultivation system that farmers in the research area apply has been analysed as rain-fed, labour-intensive, small-scale agriculture with dominant subsistence elements and very little capital input. Traditional knowledge and traded labour skills play an important role in applying cultural strategies of cultivation. Since pearl millet is known for its low demands in terms of soil quality and rainfall, it is the main staple crop, followed by maize. Millet is grown in distant fields, which are located in inter-dune valleys. Gardens, located near homesteads are used

Photo 9: Kavango homestead. Photo: Alexander Gröngröft.

Photo 10: Kraal with cattle. Photo: Alexander Gröngröft.

Photo 11: Field with mixture of Bambara Groundnut (*Vigna subterranea*) and millet. Photo: Alexander Gröngröft.

Photo 12: Bundles of grass piled up alongside the road for trade. Photo: Alexander Gröngröft.

Photo 13: Steel ploughs for ox drawn ploughing. Photo: Alexander Gröngröft.

Photo 14: Mahangu field. Photo: Michael Pröpper.

to cultivate legumes and cucurbits. These are often intercropped with maize and sorghum. Non-food cash crops such as *Jatropha curcas*, cotton, or tobacco have not been cultivated in the study area. Fields in the central Kavango Region are not irrigated and herbicides, pesticides, and fertilisers are not used. There are also few bird-protection measures being applied. About 90% of farmers in the research area use ox-drawn steel ploughs, but do not practise shifting cultivation, since people stay on one plot as long as possible and expand fields along the edges. Crop rotation and strategic fallow periods are also uncommon either.

Soil properties as influences for agricultural performance were investigated. The brown to dark inter-dune soils are the locally preferred soils for cultivation and cropping. They can be classified as Haplic Arenosols of a lower acidity, a slightly increased clay content, a reddish or dark brown or even grey colour, and a enriched nutrient content. However, the overall fertility of the soils in the region is generally low, and due to the dune/inter-dune differences, the nutritional status of the soils is highly variable. On the fields currently cropped nitrogen and especially phosphorus are deficient and the very low organic carbon content of mostly below 0.5% is critical since this restricts the Cation Exchange Capacity (CEC) as well as the water retention potential in these sandy soils. Likewise there exists a high risk of nutrient leaching and the low nutrient reserve in most profiles due to the sandy substrate.

Low yields are further aggravated by the fact that nitrogen fixing bacteria, which are common in the root nodules of many species of the legume family *Fabaceae* (here cultivated peanuts, groundnuts, different beans) are missing in the cropped cultivars. Root-associated nitrogen fixation through these microorganisms might contribute to a more sustainable production of millet, maize, and sorghum. Microorganisms may improve yields by promoting the growth of plants, through the biocontrol of pathogens, and by increasing the tolerance of plants to stress. Therefore, endophytic bacteria residing in roots of these crops were isolated and characterised with respect to their taxonomic affiliation and putative plant-growth-promoting characteristics. A diverse range of partially novel bacteria was detected, which contains promising candidates for application in sustainable agricultural management.

Looking closer into the causes and explanations for human cultivation various dimensions had to be considered. An analysis of the agricultural productivity was conducted. It turned out that the average field size of 9.8 ha (median 7.2 ± 8.9 ha) is larger than so far assumed in other studies. Fields have partly polygonal cores that are surrounded by a frayed edge of expansions and/or fallows. Land-productivity is actually far lower than all other figures that can be found in the literature. Average yields of 95 kg/ha are clearly insufficient to sustain food security of households and a key household strategy to counter shortages, therefore, is the expansion of fields where sufficient labour input is available.

Farming activities are constrained by poverty and the lack of available capital. The physical capital of households is limited and is mainly produced from natural resources. No household in the complete research sample possessed and/or used a tractor and 90% of the people in our sample were ploughing their fields exclusively with ox-drawn steel ploughs. Despite the fact that cattle have a very high cultural value only about half of all households own cattle and a plough. A larger fraction of households in the whole sample have to rent ploughing as a service that they will have to pay or work for.

Similarly, the possibilities for rural households to generate financial capital are limited and are concentrated on rather limited off-farm labour activities, remittances, and pensions. High transaction costs to store financial capital are compensated for by investing surplus money in livestock—which functions next to draught power as an alternative currency, medium of capital accumulation, bank account and insurance against misfortunes and food shortages. Therefore, the absence of adapted capital markets increases the pressure on natural resources and inhibits that savings are used productively for capital investments as a basis for development.

Under these conditions it was found that the perceptions and environmental knowledge of Kavango farmers are clustered around utilitarian criteria, which suggests that ‘farmers know best what they use most’. In this context a clear trade-off between food security and native biomass conservation could be quantified on the basis of the modelling exercise. If natural resource conservation were imposed on people living in the area and if it went beyond a certain quantified limit then that would threaten food security to a major degree.

Local farming knowledge, applications, technological preferences, and cropping styles were found to be heterogeneous and guided by few common rules. Similarly, farmers seemed to lack explanatory models for some of their observations (e.g. for the lack of soil fertility) and the explanations of 25 farmers for soil fatigue were diverse. Knowledge on sustainable intensification as a short term strategy to reduce pressure on biodiversity—ideally transferred through extension services—was found to be deficient. Cultural rules about the season, the availability of labour, draught power, and the individual status of clearing/cleaning of fields determine the decision about the convenient point in time to start ploughing. Ploughing is immediately followed by sowing, a practice that is done by the women, which again follows cultural rules. A crucial point here is the fact that the ploughing/sowing point and the onset of the rainy season can be far apart, hence the seeds can lie for longer periods in the dry top-soils heated by the sun.

Of importance is the social embeddedness of all environmental decisions that subsistence farmers have to come to. It has been found that the environmental decisions of people in this region are strongly influenced by social ties and that kinship ties play a major role. Such structures of social organisation embody a set of rules, which are themselves institutions, which influence individual action. Likewise, farming decisions are influenced by domestic problems, little access to labour and goods markets, and highly prevalent cosmological models like the omnipresence of witchcraft convictions (Pröpper, unpublished data).

Photo 15: Dead tree with visible marks of fire. Photo: Alexander Gröngröft.

Photo 16: Mahangu field. Photo: Michael Pröpper.

The ownership status of crop land is unclear and contradictions exist both in the law books and in the perception of stakeholders. Unclear property rights reduce the sense of ownership for natural resources and incentives for a long term sustainable resource management.

In particular, in an environment where institutional clarity is lacking, farmers tend to rely on the traditional authority system and customary law that is culturally close to them, since this legal culture is deeply interwoven into other aspects of Kavango life. Traditional authorities play a central role in resource protection and the dissemination of information and awareness. Likewise, the rural population opposes the formalisation of customary farming rights as unjust and opposed to traditional farming and land management practices. Farmers fear that the reform will interfere with their resource management powers and use potential. Considering the low capacity of government organisations to monitor and enforce natural resource use regulations it should be noted that role that traditional authorities play in the governance of land related issues and conflict resolution can not be easily replaced. Mutual scepticism and distrust between the system of traditional authorities and the state has been identified. Statutory organisations, which have been established for resource protection are often perceived as opponents, instead of partners. State organs of resource management and law enforcement are understaffed and under-equipped to ensure effective resource management and protection. Under these conditions the potential for resource users and traditional authorities to provide institutional services is insufficiently capitalised.

In a last step the introduction of fees for landuse was modelled. Results prove that externally enforced fees will not help to prevent the expansion of cultivated fields. A fee system, which is related to the prevailing permit system for natural resource exploitation will not encourage the intended change in landuse behaviour. This system does not provide sufficient incentives to prevent the clearing of forest for crop production.

1.9 Discussion and steps forward

We have shown that the expansion of agricultural clearing is driven by a multitude of endogenous and exogenous ecological and social causes. Without further changes, the ongoing processes are likely to lead to the following negative interlinked consequences:

- a reduction of overall tree density and ongoing woodland conversion even of areas, which are unsuitable for cropping;
- an increase in the extent and frequency of fire even in woodlands, which are not used for wood harvesting, livestock production and collection of non-timber forest products;
- a further reduction in biodiversity and ecosystem services;
- an increase in food insecurity,
- social degradation and rural poverty.

Simultaneously, crop production and the clearing of bush and forest for agriculture are key cultural strategies to prepare land for livelihood purposes. Biodiversity conservation cannot be thought of in isolation from the people that directly use and depend on it. Their well-being is inextricably linked to ecosystem services. Subsistence agriculture, as well as the actual manual activity of clearing, is an integral part of culturally grown forms of landuse. Cropping is linked to well-being in the studied area and all recommendations for an improvement of the future situation have to consider other fields of social interaction including the structures and goals of governance.

In this situation the challenge is to find ways, scenarios and reforms that improve and enhance soil, ecosystem and social resilience. The goal will be to mitigate the trade-off between sustainable landuse and well-being, to decrease the uncontrolled expansion and simultaneously increase yields on existing plots. Further crucial points for a feasible scenario include the security of rights and access to information, legal security, the allocation of defined amounts of water and energy supply, the development of infrastructure and markets, and the involvement of landusers in discussions and decisions over management, knowledge transfer, ownership and empowerment.

Comparing the status quo that has been analysed to alternatives of how to improve system performance, we have clearly exposed that in several areas the potential to enhance the Kavango crop-system performance has as yet been insufficiently tapped (see also Lal 2010).

We have shown that significant improvements in soil quality are possible if nutrient cycles are kept closed and if organic carbon (as a main factor of soil fertility, besides the clay content) is managed carefully. This can be done for example by non-tillage management and by adding natural nutrients, preferentially on planting plots to concentrate manpower and resources exclusively on the crops and not the whole fields. These techniques also bypass the need of oxen and ploughs. The use of tractors or other machinery might not be a long term solution, since more intensive cropping methods have a much stronger negative impact on soil properties and must always be combined with careful and intensive preservation management to be sustainable. The improvement of the soil quality is closely linked to the farming system. Therefore, an optimum of effort, yield and long-term sustainability has to be elaborated by experimental trials and training programmes under given conditions, with local capacities and under the decisions of local stakeholders. These trials should comprise experiments, which increase the organic carbon and nutrients in the soil (e.g. by application of cattle manure, composts, crop residues) to enhance root nodulation for nitrogen fixation as well as trials, which measure the effect of applying natural carbonates on the improvement in the soil base status. Nevertheless, the improvements of soil quality should be restricted to the inter-dune areas, which are more suitable for cropping and the field expansion to dune soils should be avoided. The trials should be accompanied by researchers from the natural sciences and social sciences who would be able to advise on experimental design and who would be able to investigate system changes, constraints, problems and ways ahead.

Additionally we have shown that a change in the established farming system, especially the alteration of farm operations and technology-changes (Lal 2010), holds promise for performance improvements. The current farming system strongly rests on the assumption that ploughing (cattle draught and infrequently tractors) is the best method of agriculture for the region. However, the assumption that in the absence of capital and artificial fertilisers an expanded field will lead to increased productivity and greater output turns out to be simplistic. Equally problematic is the assumption that more labour-input will generate a higher productivity. Fast and effective (thorough) clearing, ploughing, and weeding certainly will bring some limited improvement. But, given the constraints of soils and low capital-input, an increase of manual labour will have only limited returns. Hence, experimenting could be directed towards alternative farming systems and technologies like **conservation agriculture** (CA), which promise higher yields through a **methodical change**. Likewise changes in the sowing techniques or the establishment of drip irrigation gardening, which is currently being tested along the Kavango River might be promising improvements.

However, such alternative methodical suggestions cannot be enforced or imposed against considerable cultural and knowledge gaps of stakeholders at different scales with different interests and powers. Hence, the crucial aspects of knowledge transfer, value awareness and empowerment need to be negotiated in a polycentric process that explicitly involves local farmers. Experiments with alternative methods have to be communicated in a qualified manner and by qualified extension personnel, which regularly monitors the training success. Likewise, such experiments should be accompanied by natural and social science monitoring with clear stakeholder involvement. So far, long-term scientific monitoring and investigations on ecosystem services does not exist, although topics for scientific research with strong linkage to the farming system have been identified. These include, inter alia, the sustainability of the additional use of groundwater for small-scale gardening combined with the use of manure or compost on a small-scale level; the quality and quantity of organic carbon as a soil component for stabilising nutrient reserves (also under the influence of fire); the role of trees within cultivated fields (which act as fertile islands due to water and nutrient uptake and through their ability to change the soil water balance); the occurrence and quality of natural carbonate reservoirs (calcretes) in the region for their potential as a magnesium fertiliser; the introduction of nitrogen-fixing bacteria.

Apart from these rather tangible steps ahead, we have also assessed some of the complex social backgrounds of the cultivation system. We have outlined that especially the institutional frame that guides resource protection exposes **legislative inconsistencies**. Also, the lack of capacity within the statutory executive causes considerable voids and uncertainties in resource protection. Furthermore, an awareness of land related rights and duties is widely missing among local users. Results indicate that the current tenure arrangements within the Kavango Region provide ambiguous incentives for natural resource management while attempts to raise ownership by empowering people through information and involvement are insufficient. The registration of individual land titles is costly, inflexible to accommodate for common cultural practices such as traditional matrilineal inheritance patterns and social mobility, and is locally rejected. Against this background we have further outlined that a fee system is also unlikely to produce effective results. However, statutory as well as customary agents could increase their efforts to promote ownership by clarifying the legal status, empowering people through information, raising awareness of the values and limitations of natural resources, and involve different stakeholders in a stronger cooperative system. In a constructive polycentric setup different stakeholders such as local resource users, traditional authorities and state law enforcement could establish a cooperative governance framework, which would make use of the advantages and compensate for each others' shortcomings.

The most complex aspect of high indirect importance for enhancing ecosystem resilience, is the sustainable improvement of socioeconomic frame conditions for impoverished landusers. We have shown that capital deficiencies and lack of farm income obstruct household food security, economic success and hence, their well-being. Improvement in labour and goods market and capital access, infrastructure development (e.g. through facilitation of micro-credit-schemes and marketing cooperatives) should be envisaged. Such measures could reduce the reliance on livestock as the main means of capital accumulation.

In sum low-capital input and locally adapted agricultural intensification can reduce pressure on forests and improve food security in the Kavango Region. Nonetheless, any institutional and technical change only has a chance to be implemented if the cultural and moral value systems of the stakeholders are considered. It has to be emphasised, though, that traditional mechanisms and institutions of security networks and models of traditional economy and cultural land-use knowledge are a stabilising factor of the status quo. There is no short term replacement. If they are eroded by individualised consumerism, they will have to be replaced by statutory education, jobs, welfare, and a functioning social security, health system and waste disposal system—all of which are missing so far.

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References

Acquah, E.T., Davis, R. (1997): Stimulating indigenous agribusiness development in the northern communal areas of Namibia: a concept paper. – Technical Paper No. 73. Washington: USAID.

Ashley, C. (2000): Incentives affecting biodiversity conservation and sustainable use: the case of land use options in Namibia. – Research Discussion Paper No. 13: 1–22. Windhoek: Directorate of Environmental Affairs Ministry of Environment and Tourism.

Backhaus, K., Erichson, B., Plinke, W., Weiber, R. (2006): Multivariate Analysemethoden: eine anwendungsorientierte Einführung. Ed. 11. – Berlin: Springer.

Bationo, A., Christiansen, C.B., Klaji, M.C. (1993): The effect of crop residue and fertiliser use on pearl millet yields in Niger. – Fertiliser Research **34**: 251–258.

Biggs, R., Simons, H., Bakkenes, M., Scholes, R.J., Eickhout, B., Vuuren, D. van, Alkemade, R. (2008): Scenarios of biodiversity loss in southern Africa in the 21st century. – Global Environmental Change **18**: 296–309.

Burbano, C.S., Reinhold-Hurek, B., Hurek, T. (2010): LNA-substituted degenerate primers improve detection of nitrogenase gene transcription in environmental samples. – Environmental Microbiology Reports **2**: 251–257.

Burke, A. (2002): Present vegetation in the Kavango. – Journal of the Namibia Scientific Society **50**: 133–145.

Coolen, M.J.L., Overmann, J. (2000): Functional exoenzymes as indicators of metabolically active bacteria in up to 124,000 year-old sapropel layers of the eastern Mediterranean Sea. – Applied and Environmental Microbiolology **66**: 2589–2598.

Demba Diallo, M., Reinhold-Hurek, B., Hurek, T. (2008): Evaluation of PCR primers for universal nifH gene targeting and for assessment of transcribed nifH pools in roots of *Oryza longistaminata* with and without low nitrogen input. – FEMS Microbiology Ecology **65**: 220–228.

Duivenbooden, N. van, Wit, C.T. de, Keulen, H. van (1996): Nitrogen, phosphorus and potassium relations in five major cereals reviewed in respect to fertiliser recommendations using simulation modelling. – Fertiliser Research **44**: 37–49.

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.

FAO (2001): Nutrition country profiles – Namibia. – Rome: FAO.

FSSA (ed.) (2007): Fertiliser handbook. Ed. 6. – Lynnwood Ridge, FSSA.

Fox, T. (2008): Investigating the dynamics of subsistence cultivation in the tree savanna of North-East Namibia by means of remote sensing. – Thesis for Master of Science in Geomatics. Karlsruhe & Oberpfaffenhofen: Faculty of Geomatics International Master Course Geomatics, Karlsruhe University of Applied Sciences & German Aerospace Center (DLR).

Fuller, B., Zyl, D. van (2006): Silently starving: a new form of famine among small scale farming households affected by the HIV epidemic? – NEPRU Working Paper No. 107: i–viii, 1–45.

Gascho, G.J., Menezes, R.S.C., Hanna, W.W., Hubbard, R.,K., Wilson, J.P. (1995): Nutrient requirements of pearl millet. – Proceedings of the First National Pearl Millet Symposium. Tifton: University of Georgia.

Geist, H.J., Lambin, E.F. (2002): Proximate causes and underlying driving forces of tropical deforestation. – BioScience **52**: 143–150.

Gessner, U., Klein, D., Conrad, C., Schmidt, M., Dech, S. (2009): Towards an automated estimation of vegetation cover fractions on multiple scales: examples of eastern and southern Africa. – Proceedings of the 33rd International Symposium on Remote Sensing of Environment May 4-8 2009, Stresa, Italy: 4.

Gich, F., Schubert, K., Bruns, A., Hoffelner, H., Overmann, J. (2005): Specific detection, isolation and characterisation of selected, previously uncultured members of freshwater bacterioplankton. – Applied and Environmental Microbiology **71**: 5908–5919.

Government of the Republic of Namibia (2001): Second national development plan (NDP2) 2001/2002–2005/2006 **2**: Regional development perspectives. – Windhoek: National Planning Commission.

Government of the Republic of Namibia (2004): Namibia vision 2030. – Windhoek: Office of the President.

Hailwa, J.S. (2002): Tropical secondary forest management in Africa: realities and perspectives. – Namibia Country Paper. Workshop on Tropical Secondary Forest Management in Africa, Nairobi, 2002. http://www.fao.org/Docrep/006/J0628e/J0628E58.htm

Hange, A., Kakuru, E., Low, A., Bagnall-Oakley, H. (1999): The impact of HIV/AIDS on gender burdens and household incomes in Kavango: technology and policy implications. – Discussion Paper No 4. Windhoek: Ministry of Agriculture, Water and Rural Development, Division Agricultural Planning, Directorate of Planning, Department of Agriculture and Rural Development.

Hartemink, A.E. (2006): Soil fertility decline: definitions and assessment. – Encyclopedia of Soil Science. Ed. 2: 1618–1621. DOI: 10.1081/E-ESS-120041235.

Hebel, A. (1995): Einfluß der organischen Substanz auf die räumliche und zeitliche Variabilität des Perlhirse-Wachstums auf Luvic Arenosolen der Sahel (Sadoré/Niger). – Hohenheimer Bodenkundliche Hefte 24. Stuttgart: Universität Hohenheim.

Hecht, J. (2009): Decision making of rural farm households in Namibia: lessons learned from multi-annnual programming optimisation models. – Dissertation, submitted. Giessen: Institute of Agricultural Policy and Market Research, Justus-Liebig-University of Giessen.

Hinz, M.O. (1995): Customary land law and the implications for forests, trees and plants (final report). – Technical Co-operation Program TCP/NAM/4453. Windhoek: Ministry of Environment and Tourism & FAO.

Hurek, T., Reinhold-Hurek, B. (2005): Molecular ecology of N2-fixing microbes associated with graminaceous plants. – In: Werner, D., Newton, W.E. (eds,): Agriculture, forestry, ecology and the environment: 173–198. Dordrecht: Kluwer Academic Publishers.

Hurek, T., Handley, L., Reinhold-Hurek, B., Piché, Y. (2002): *Azoarcus* grass endophytes contribute fixed nitrogen to the plant in an unculturable state. – Molecular Plant-Microbe Interactions **15**: 233–242.

Jones, B.T.B., Cownie, D. (2001): Socio-ecological survey report for the Kavango region (Namibia 2001). – Windhoek: Every River Has Its People Project.

Keyler, S.K. (1996): Economics of the Namibian millet subsector. – PhD thesis. Lansing: Department of Agricultural Economics, Michigan State University.

Klein Goldewijk, C.G.M, Battjes, J.J. (1997): A hundred year database (1890-1990) database for integrated environmental assessments (HYDE, version 1.1). – Bilthoven: National Institute of Public Health and the Environment.

Klein Goldewijk, K., Ramankutty, N. (2004): Land cover change over the last three centuries due to human activities: the availability of new global data sets. – GeoJournal **61**: 335–344.

Knauth, S., Hurek, T., Brar, D., Reinhold-Hurek, B. (2005): Influence of different *Oryza* cultivars on expression of nifH gene pools in roots of rice. – Environmental Microbiology **7**: 1725–1733.

Koch, I.H., Gich, F., Dunfield, P.F., Overmann, J. (2008): *Edaphobacter modestus* gen. nov., sp. nov., and *Edaphobacter aggregans* sp. nov., two novel acidobacteria isolated from alpine and forest soils. – International Journal of Systematic and Evolutionary Bacteriology **58**: 1114–1122.

Krogh, L. (1997): Field and village nutrient balances in millet cultivation in northern Burkina Faso: a village case study. – Journal of Arid Environments **35**: 147–159.

LAC (2003): Guide to the communal land reform Act No 5 of 2002. – Windhoek: Legal Assistance Centre & Advocacy Unit Namibia National Farmers Union.

Lal, R. (2010): Managing soils for a warming earth in a food-insecure and energy-starved world. – Journal of Plant Nutrition and Soil Science **173**: 4–15.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B, Angelsen, A., Bruce, J.W., Coomes, O.T, Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C., Xu, J. (2001): The causes of land-use and land-cover change: moving beyond the myths. – Global Environmental Change **11**: 261–269.

Landon, J.R. (eds.) (1991): Booker tropical soil manual. – Harlow: Longman.

Likuwa, K. (2001): Djwaini – a coffin with your recruit number on. The experience of contract migrant labourers from Kavango to South African Gold Mines 1944-1977. – BE thesis in History. Windhoek: UNAM.

Loots, S. (2005): A Red Data Book of Namibian plants. – Southern African Botanical Diversity Network Report No. 38. Pretoria & Windhoek: SABONET.

Mapaure, C. (2008): Biodiversity at crossroads: internal conflict of laws in the conservation of forests in the Kavango, Namibia. – LLB thesis. Windhoek: University of Namibia.

Matsaert, H., Mutwamwezi, E., Kakukuru, E. (1998): Getting to know rural livelihoods in Kavango through case study monitoring. – Kavango Farming System Research and Extension (KFSRE) Working Document No. 26. Rundu: KFSRE.

Masters, W.A., Dalton, TJ. (1998): Pasture taxes and agricultural intensification in southern Mali. – Agricultural Economics **19**: 27–32.

Mayer, M. (2008): Stoffumsetzungen in Bakteriengemeinschaften und in nährstoffarmen Böden Namibias. – PhD thesis. München: Ludwig-Maximilians-Universität München.

Mendelsohn, J., Obeid, S. el (2003): Sand and water. A profile of the Kavango region. – Cape Town: Struik.

Mendelsohn, J., Jarvis, A., Roberts, C., Robertson, T. (2002): Atlas of Namibia: a portrait of the land and its people. – Cape Town: David Philip Publishers.

Millennium Ecosystem Assessment (2005): Ecosystems and human well-being: biodiversity synthesis. – Washington, D.C.: World Resources Institute.

Ministry of Agriculture Water and Rural Development (2003): Baseline survey of the impact of agricultural extension services in the Kavango Region. – Rundu: MAWRD.

Mutwamwezi, E., Matsaert, H. (1998): Crop production in Kavango: findings of case study monitoring 1995-1997. – KFSRE Working Document Number 29. Rundu: Kavango Farming System Research and Extension.

Namwoonde, N. E. (2008): A rejected import: registration of customary land rights in Kavango. – LLB thesis. Windhoek: University of Namibia.

National Planning Commission (2003): 2001 population and housing census. National report. Basic analysis with highlights. – Windhoek: NPC, Central Bureau of Statistics.

Oades, J.M. (1988): The retention of organic matter in soils. – Biogeochemistry **5**: 35–70.

Pagel, H., Enzmannm J., Mutscher, H. (1981): Pflanzennährstoffe in tropischen Böden – ihre Bestimmung und Bewertung. – Berlin: VEB Deutscher Landwirtschaftsverlag.

Petersen, A. (2008): Pedodiversity of southern African drylands. – Hamburger Bodenkundliche Arbeiten **61**: 1–347.

Peverill, K.I. Sparrow, L.A., Reuter, D.J. (eds.) (1999): Soil analysis: an interpretation manual. – Collingwood: CSIRO Publishing.

Phororo, H. (2001): Food crops or cash crops in the northern communal areas of Namibia: setting a framework for a research agenda. – Windhoek: NEPRU.

Post, W.M., Mann, L.K. (1990): Changes in soil organic carbon and nitrogen as a result of cultivation. – In: Bouwman, A.F. (eds.): Soils and the greenhouse effect: 401–406. Hoboken: John Wiley & Sons.

Pröpper, M. (2009a): Culture and biodiversity in central Kavango, Namibia. – Berlin: Reimer.

Pröpper, M. (2009b): Sawing Kavango timber commons: levels of action and agency upon local natural capital. – In: Greiner, C., Kokot, W. (eds.): Networks, resources and economic action. Ethnographic case studies in honor of Hartmut Lang: 171–188. Berlin: Reimer.

Pröpper, M., Gruber, M. (2007): Wiza Wetu! Our Forest! Ethnographic Awareness. – Film, 50 min. Hamburg: Institute for Social Anthropology, University of Hamburg for BIOTA/BMBF.

Ramankutty, N., Foley, J.A.(1999): Estimating historical changes in global land cover: croplands from 1700 to 1992. – Global Biogeochemical Cycles **13**: 997–1027.

Republic of Namibia (1990): The constitution of the Republic of Namibia. – Windhoek: Republic of Namibia.

Republic of Namibia (2000): Traditional Authorities Act No. 25 of 2000. – Windhoek: Republic of Namibia.

Republic of Namibia (2002): Communal Land Reform Act No. 5 of 2002. – Government Notice No. 137. Government Gazette of the Republic of Namibia No. 2787: 1–35.

Republic of Namibia (2003): Regulations made in terms of the Communal Land Reform Act, 2002. – Windhoek: Ministry of Lands, Resettlement and Rehabilitation.

Republic of Namibia (2008): A review of poverty and inequality in Namibia. – Windhoek: National Planning Commission.

Romann, E. (2008): Kulturunabhängige Untersuchung von Bodenproben aus einer semi-ariden Region Namibias. – PhD thesis. München: Ludwig-Maximilians-Universität München.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H. (2000): Global biodiversity scenarios for the year 2100. – Science **287**: 1770–1774.

Sanchez, P.A., Palma, C.A., Buol, S.W. (2003): Fertility capability soil classification: a tool to help assess soil quality in the tropics. – Geoderma **114**: 157–185.

Sibeene, P. (2008): Kavango in fight against poverty. – New Era, September 3, 2008. www.newera.com.na/archives.php??id=22675&date=2008-09-03 [acc. 03.09.2008].

SSD (1996): Credit and savings in Kavango and Caprivi Namibia. – SSD Research Report No: 27. Windhoek: Social Sciences Division, University of Namibia.

Strohbach, B.J., Petersen, A. (2007): Vegetation of the central Kavango woodlands in Namibia: an example from the Mile 46 Livestock Development Centre. – South African Journal of Botany **73**: 391–401.

Tano, K., Kamuango, M., Faminow, M., Swallow, B. (2003): Using conjoint analysis to estimate farmers preferences for cattle traits in West Africa. – Ecological Economics **45**: 393–407.

Tapscott, C. (1994): Land reform versus agrarian reform in northern Namibia: a case study from the Gciriku district of Okavango. – SSD Discussion Paper No. 7. Windhoek: Social Sciences Division, University of Namibia.

Thomas, D.S.G., O'Connor, P.W., Bateman, M.D., Shaw, P.A., Stokes, S., Nash, D.J. (2000): Dune activity as a record of late Quaternary aridity in the Northern Kalahari: new evidence from northern Namibia interpreted in the context of regional arid and humid chronologies. – Palaeogeography, Palaeoclimatology, Palaeoecology **156**: 243–259.

Turner II, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., Meyer, W.B. (1990): The earth as transformed by human action: global and regional changes in the biosphere over the past 300 years. – Cambridge: Cambridge University Press.

Verlinden, A., Laamanen, R. (2006): Long term fire scar monitoring with remote sensing in Northern Namibia: Relations between fire frequency, rainfall, land cover, fire management and trees. – Environmental Monitoring and Assessment **112**: 231–253.

Vitousek, P.M., Cassman, K., Cleveland, C., Crews, T., Field, C.B., Grimm, N.B., Howarth, R.W., Marino, R., Martinelli, L., Rastetter, E.B., Sprent, J.I. (2002): Towards an ecological understanding of biological nitrogen fixation. – Biogechemistry **57/58**: 1–45.

Vogel, M. (2006): Erfassung von Vegetationsveränderungen in Namibia mit Hilfe von Fernerkundungs-Change-Detection-Verfahren und unter Berücksichtigung rezenter Niederschlagsereignisse. Assessment of Vegetation Change in Namibia using Remote Change Detection Techniques considering Precipitation Data. – Dissertation. Würzburg: Institut für Geographie, Julius-Maximilians-Universität Würzburg.

Werner, W. (2008): Protection for women in Namibia's Communal Land Reform Act: is it working? – Windhoek: Legal Assistance Centre.

Werner, W. (2002): Access to resources: livelihood options and strategies. – Windhoek: NEPRU/DRFN.

Wisch, U. (2008): Soil fertility of dryland farming systems in the Kavango region, Namibia. – Diplom thesis. Hamburg: University of Hamburg.

Yaron, G., Janssen, G., Maaberua, U. (1992): Rural development in the Okavango region of Namibia: an assessment of needs, opportunities and constraints. – Windhoek: Gamsberg Macmillan.

Zhang, L., Hurek, T., Reinhold-Hurek, B. (2005): Position of the fluorescent label is a crucial factor determining signal intensity in microarray hybridisations. – Nucleic Acids Research **33**: e166.

Zhang, L., Hurek, T., Reinhold-Hurek, B. (2007): A nifH-based oligonucleotide microarray for functional diagnostics of nitrogen-fixing microorganisms. – Microbial Ecology **53**: 456–470.

Zul, D. (2008): Molecular ecology and cultivation dependent analysis of soil microbial communities. – PhD thesis. München: Ludwig-Maximilians-Universität München.

Zul, D., Denzel, S., Kotz, A., Overmann, J. (2007): Effects of plant biomass, plant diversity and water content on bacterial communities in soil lysimeters: implications for the determinants of bacterial diversity. – Applied and Environmental Microbiology **73**: 6916–6929.

Bush encroached rangeland in the Thornbush Savanna. Photo: N. Dreber.

Part IV

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Impacts of landuse and climate change on the dynamics and biodiversity in the Thornbush Savanna Biome

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Summary: In this chapter we summarise results of the long-term interdisciplinary BIOTA study investigating the impacts of landuse and climate change on the dynamics and sustainable use of biodiversity in the Thornbush Savanna Biome of southern Africa. This study successfully integrated remote sensing methods, eco-hydrological approaches, and ecological research with socio-economic aspects by combining empirical and modelling approaches. Based on a summary of current knowledge and key challenges, we describe in-depth analyses of the causes and mechanisms of vegetation dynamics in the focal thornbush savannas and the consequences of the resulting vegetation patterns for animal diversity and a single medicinal plant species. These analyses provided risk assessments of vegetation and animal diversity based on future environmental scenarios, and enabled the formulation of recommendations for landusers and conservation planners and the identification of future research needs.

2.1 Introduction: current knowledge and key challenges

[F. Jeltsch, N. Blaum, E. Rossmanith & D. Lohmann]

According to the Millennium Ecosystem Assessment (2005) the greatest pressure on dryland ecosystem services takes place in regions of intermediate aridity and not, as might be expected, in dry subhumid areas where population density is highest, or in hyperarid areas, where population is lowest. The high overexploitation of services is inferred by physical, biological, and social phenomena—soil erosion, reduced biodiversity and biological productivity, and reduced income expressed by reduced human well-being—and it is reflected by the highest rate of infant mortality and hunger among children (Millennium Ecosystem Assessment 2005: chapter 22). This and the fact that (i) drylands cover about 41% of Earth's land surface and are inhabited by more than 2 billion people (about one third of the world's population) and (ii) dryland populations on average lag far behind the rest of the world in terms of human well-being and development indicators (Millennium Ecosystem Assessment 2005), emphasises the need to focus dryland research on regions of intermediate aridity.

Arid and semi-arid Thornbush Savannas of south-western Africa are such hot spots with regard to the relevance of biodiversity, ecosystem processes and services for current and future livelihood of millions of households (Ericson & Watson 2009). They can function as a model-region for a broad range of drylands, especially non-humid savannas, worldwide—in particular as projected climatic changes for most subhumid and semiarid savanna regions indicate major shifts in precipitation towards drier conditions (Solomon et al. 2007). Therefore, research findings especially for the drier end of the savanna continuum are likely to become relevant for areas that are currently more humid.

Previous research in the Thornbush Savanna regions of south-western Africa has shown that management strategies related to current landuse (e.g. extensive livestock production) can be problematic in this fragile dryland ecosystem (e.g. Jeltsch et al. 1997a, b, Weber & Jeltsch 2000, Weber et al. 2000, Popp et al. 2009a, b). In Namibia alone about 50% of the savanna rangeland is purportedly affected (Bester 1998). Projected consequences of the current landuse strategies include desertification with increasing erosion risks in the drier savanna parts and intensified bush encroachment (i.e. the increase of un- or less palatable woody species at the cost of palatable herbaceous vegetation) in the more mesic parts. These problems are aggravated by climate change and rapid population growth. Current climate projections predict increasing temperatures, decreasing precipitation, shorter rainy seasons, and increasing intensity of rain events (Solomon et al. 2007). Desertification and degradation caused by ill-adapted land management or/and climate change are accompanied by biodiversity losses (e.g. Blaum et al. 2007a, b, c, 2009a, b, Wasiolka et al. 2010) adding further risks to ecosystem functioning and stability. Biodiversity plays a crucial role in the provision of dryland savanna ecosystem services. This includes single key species that are directly involved in the provision of a range of ecosystem services (e.g. *Acacia erioloba* in the southern Kalahari providing fuelwood, forage and food, and supporting soil development and conservation (Dean et al. 1999, see also Article III.7.2), or plant communities providing a package of services through their ground cover and structure (e.g. water regulation and soil conservation as well as forage and fuelwood provision and climate change resilience) (Millennium Ecosystem Assessment 2005: chapter 22). The biodiversity of “vegetation cover” and biological soil crusts is further linked to a diversity of arthropod species that process most of the living plant biomass, constituting the first link of nutrient cycling. Also, the replacement of the herbaceous vegetation by encroaching bush or the reduction of the litter-decomposing termite populations can impair nutrient cycling, primary production, and carbon sequestration (Whitford & Parker 1989, Zeidler et al. 2002).

Clearly, the change in the ecological environment causes economic problems as landusers depend crucially on natural resources. Key ecological and economic services within the Thornbush Savannas of south-western Africa that are at risk include livestock, game and woodfuel production. The latter service is of high relevance since more than 90% of rural households in southern Africa are still dependent on fire wood for cooking and the average household uses up to 3 tons of wood per year of which the majority is harvested from live trees (Kojwang 2000).

In this chapter we will summarise and discuss key results and their implications of almost one decade of interdisciplinary research in the arid to semi-arid Thornbush Savannas of south-western Africa.

2.2 “When is a Change a Change?”

[M. Lück-Vogel & M. Strohbach]

Background

Savannas are described as semiarid transition zones between tropical forests and deserts (Mistry 2000). This definition implies the dynamic character of the “ecotone named Savanna”, where the more humid tropical and more arid desert conditions can vary tremendously in space and time. In fact, the last nine years of interdisciplinary BIOTA work have demonstrated a high degree of variability in the dynamics of savanna vegetation at a range of spatial and temporal scales. One of the major questions several BIOTA experts dealt with was to assess the relevant changes, namely degradation processes, during the period of observation. However, it turned out that the accurate distinction between non-reversible degradation processes (directed change) and the system-inherent interannual variability (non-directed change) is a challenge on its own.

Vegetation surveys

Phytosociological surveys were conducted to better define the Thornbush Savanna vegetation in Namibia. The distributions of individual plant communities within a vegetation type were strongly related to soil characteristics. On the other hand, the individual sub-types of plant communities often showed variations of community structure and composition that could broadly be related to either landuse impacts or rainfall regime at the time of survey. In addition to the surveys, several permanent sites were used to monitor vegetation at regular intervals to gain more insight into the dynamics of the vegetation.

Namibian vegetation scientists have not yet developed a plant indicator system analogous to Ellenberg’s indicator value system, which has been used for decades to evaluate natural site conditions and potential alterations thereof due to different landuse practices on Middle Europe’s vegetation communities. However, there is already a fair understanding of which perennial (and some annual) grasses and shrubs indicate relatively sustainable or unsustainable rangeland management, although there is still much uncertainty about the ideal species composition that would indicate a highly productive, intact rangeland. This is further complicated by the dynamic nature of the herb layer. In particular the annual species are highly dynamic as rainfall regimes change annually, not only in response to the total amount of rain received, but also in terms of how that rainfall is distributed over the growing season. This observation was confirmed by the analysis of monthly rainfall data derived from the Climatic Research Unit (CRU; http://www.cru.uea.ac.uk; Hulme 1992) and vegetation development on several farms in the study area. In this analysis rainfall data were overlaid with remotely sensed NDVI data (Normalised Difference Vegetation Index) derived from NOAA-AVHRR and MODIS sensors, which provides an indication of the intensity of photosynthetic activity per area. The close relationship between rainfall and NDVI (Fig. 1) clearly shows that the vegetation responds within only a few weeks after significant rainfall events have occurred.

Furthermore, the interannual variability of plant species composition at fixed monitoring sites was recorded. The results showed that sites, which have been managed sustainably for decades might on occasion also be dominated by so-called degradation species in some years. This phenomenon is most prevalent when rainfall is distributed predominantly during the very early or very late growing season (but not equally throughout). Under these circumstances, these ruderal species are then better-adapted to germinate and grow quickly, whilst growth in the remainder of the vegetation is considerably repressed due to the otherwise unfavourable rainfall. However, the scenario may change entirely during the following growing season, again depending on rainfall distribution.

Remote Sensing

The high variability of species composition as well as total biomass recorded during the botanical surveys also had severe implications for the remote sensing work conducted during the 9 years of BIOTA research.

Vegetation mapping. One of the major goals of BIOTA was to derive a vegetation map for at least a 60 km wide strip along the BIOTA north-south transect. Using Landsat 7 ETM+ data from the rainy season 1999–2000, the vegetation units derived by the plant surveys on the Observatories and beyond served as ground truth information. The resulting vegetation map reveals the small-scale, spatial mosaic of the different vegetation units (Fig. 2). In an attempt to monitor the vegetation development over time, the classification scheme developed for imagery in one year was applied to satellite imagery of the following year. This was made possible through the use of ATCOR 2 and ATCOR 3 software, which used to radiometrically normalise the imagery beforehand (Richter 2009).

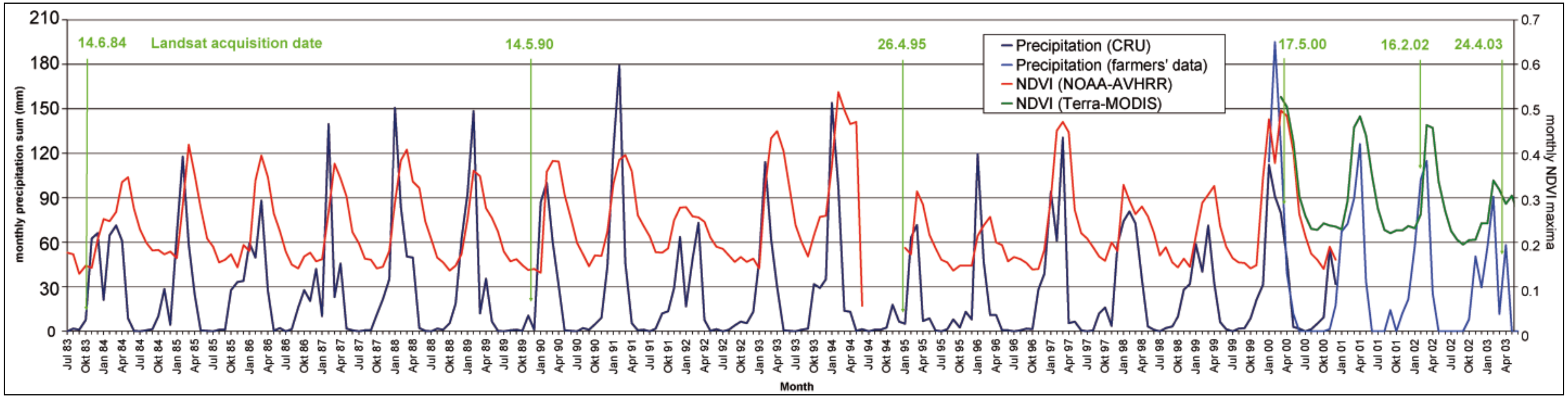

Fig. 1: Plot of monthly rainfall and NDVI development for central Namibia (area between Windhoek and Otjiwarongo) for the years 1983–2003. Green arrows indicate acquisition dates of Landsat TM imagery that was used for regional monitoring of vegetation dynamics.

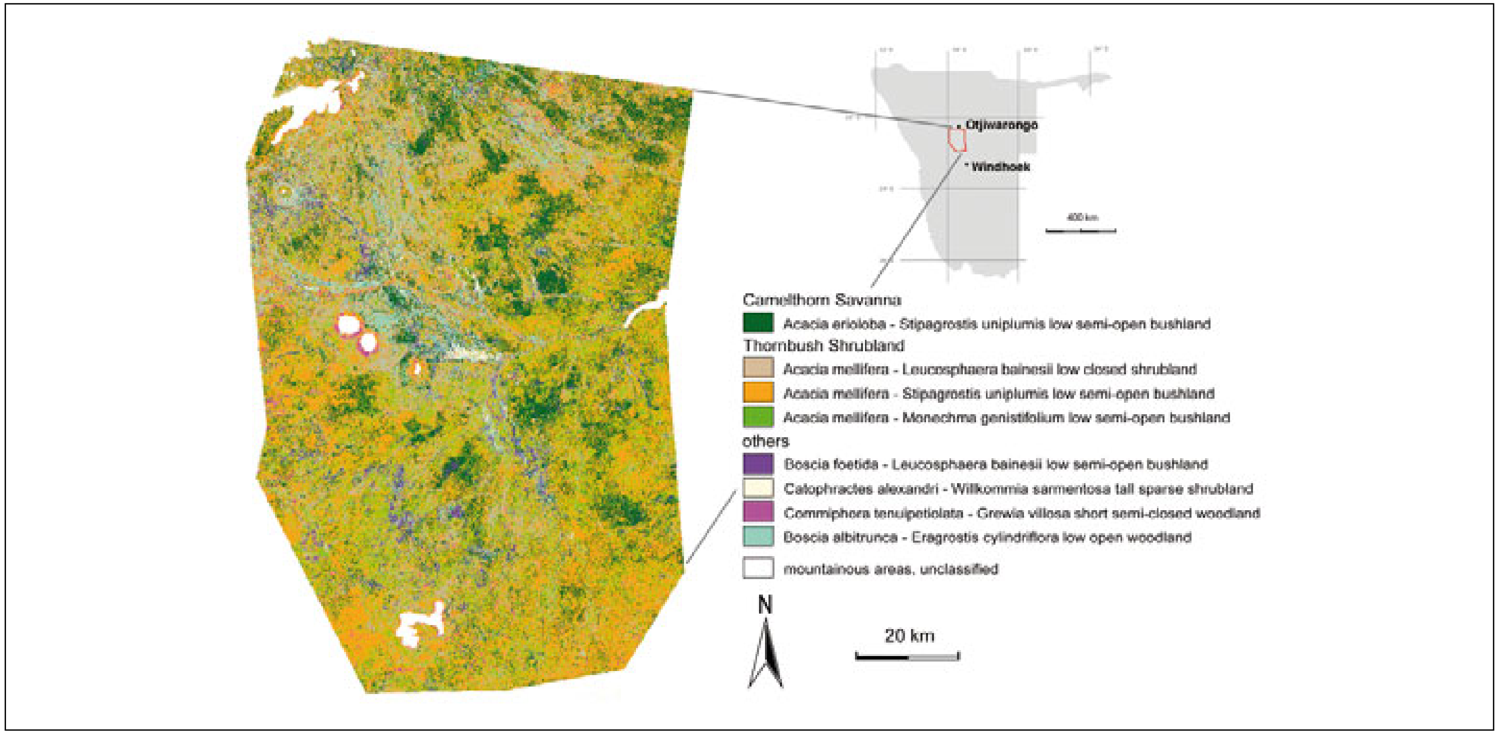

Fig. 2: Vegetation map for the area between Okahandja and Otjiwarongo, derived from Landsat 7 ETM+ imagery with a supervised Maximum Likelihood classification. Two white circles in left image centre: masked Omatako Mountains. Source: Strohbach (2002).

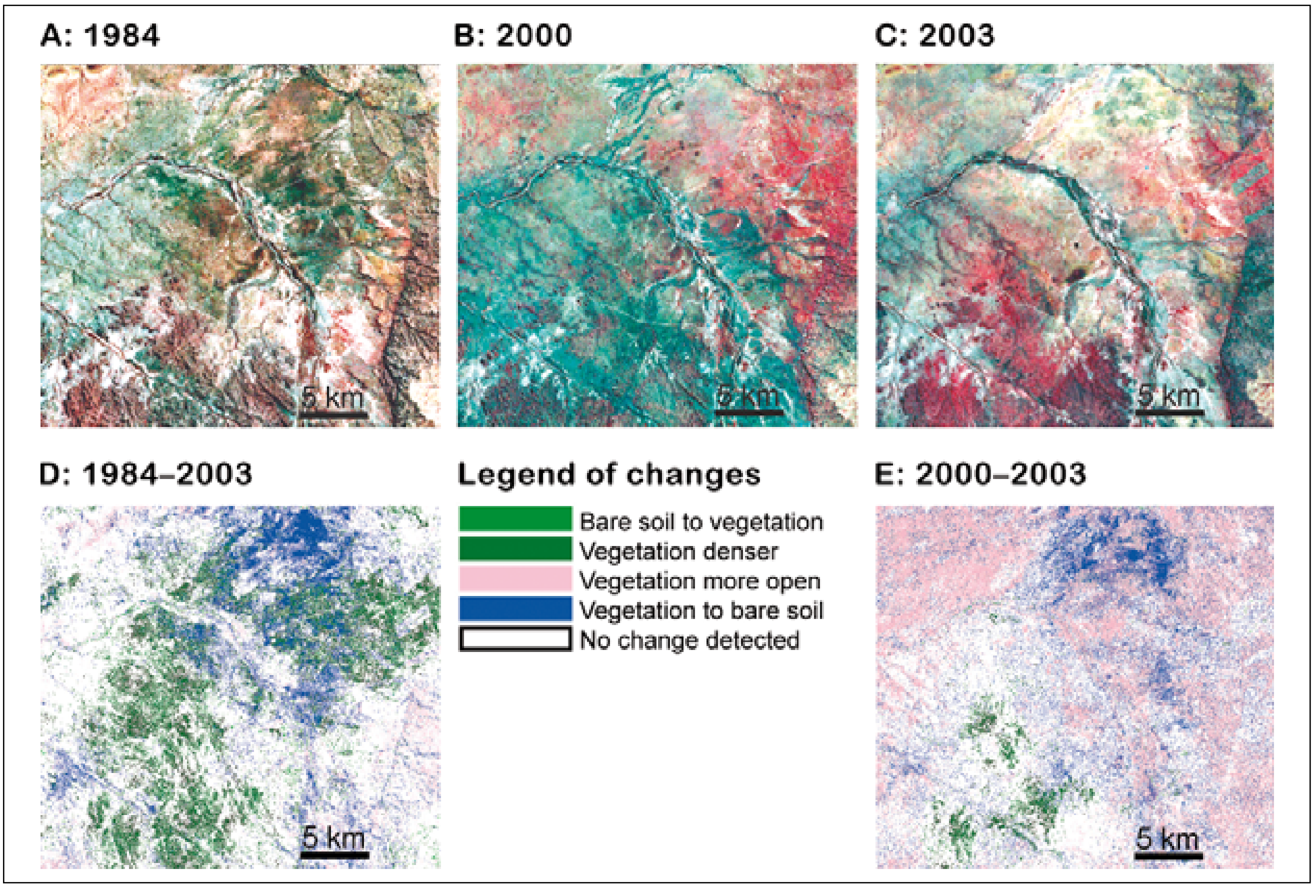

Fig. 3: Detected vegetation change for a Landsat TM subset of the area between Okahandja and Hochfeld. The image acquisition dates and rainfall history of the study area can be seen in Fig. 1. The displayed Landsat band combination for A to C is as follows: RGB: b3-b5-b4 (red-MIR-NIR). With this combination dense vegetation appears red, open-dry vegetation appears green and bare soil appears white. The rainfall history of the 1984 and 2003 images was comparable (366 mm vs. 305 mm until respective image acquisition date), but 2000 was significantly wetter (710 mm) than 2003. Thus, the shift from vegetation to bare soil evident in E above should be understood as a non-permanent, phenological response to the lower rainfall in 2003, whereas the detected increase in denser vegetation is probably related to a permanent increase in woody plants (i.e. an increase in bush encroachment). The increase in vegetation in D most likely is related to bush encroachment. Source of Landsat TM imagery: USGS.

However, the vegetation boundaries in the areas, which were compared over two years varied significantly. This led us to ask the question: “Do these changes reflect a permanent change in the vegetation on the ground?” Frequently an analysis of the rainfall data or recent landuse history (from asking the farmers) showed that the changes were not permanent changes but either reflected drought/non-drought related conditions or the impact of recent grazing events, which were superimposed on the vegetation characteristics of the study area.

Significant change processes. In order to identify the relatively permanent, directional changes that have occurred in the vegetation of the central Namibian savanna region, a Landsat TM based change analysis was conducted for the period from 1984–2003 (Vogel 2006, Vogel & Strohbach 2009). Farmers confirmed that bush encroachment, bush dieback, fires, clear cutting of bushes, and grazing impact are the most important factors leading to changes in the relative composition of woody and herbaceous species. We wanted to know if bush encroachment was indeed a significant phenomenon in this region since this process has been described for other savanna regions in southern Africa and in many other parts of the world (e.g. Sefe et al. 1996). Bush encroachment is a severe problem, as the increase in frequently dense and mono-specific woody plant communities often leads to a reduction in plant and animal diversity. Furthermore, bush encroached regions suffer significant loss in economic value, e.g. for livestock farming (de Klerk 2004). Because a vegetation unit-based approach appeared not to be suitable (see vegetation mapping challenges described above), a more robust change detection approach was developed, using a series of radiometrically-normalised multispectral Landsat TM data. The result was a map of areas where complete vegetation loss (related to “desertification”), recovery of vegetation on bare soil (restoration/rehabilitation), moderate vegetation increase (densification of woody cover: bush encroachment) and moderate decrease of vegetation (bush dieback presumably as a result of a fungal disease) were detected (Vogel 2006) (Fig. 3).

The resulting series for changes between the years 1984–1990, 1990–1995, 1995–2000, 2000–2002, 2002–2003, and 1984–2003 confirmed the high inter-annual and small-scale spatial variability in the density of the vegetation in the savanna vegetation of that region (Fig. 3). Because of this variability, it was again difficult to detect permanent and significant changes in the vegetation. While there was a close relationship between rainfall history and detected change in vegetation density (see also Fig. 1) in only a few cases, could the change in vegetation cover or density be confidently related directly to bush encroachment or desertification. Most of the detected changes had to be interpreted as phenology-related, non-significant variations in vegetation cover. It was only in areas where the observed changes in vegetation phenology differed from what was expected under a particular rainfall history that a directional change in the vegetation could be inferred with any degree of certainty.

So what are the lessons learnt?

Firstly, we suggest that we need to abandon the idea of the savanna as a monostatic constant system. Secondly, in semi-arid systems such as the observed Thornbush Savannas, we suggest that rainfall is the limiting factor for vegetation development and even single rainfall events can result in a significant response in the vegetation. Therefore we need to accept that vegetation density and also the species composition may vary considerable in space and time (even annually) in response to rainfall.

This strong phenological response to rainfall is detectable with a variety of satellite imagery instruments and processes (see also Wessels et al. 2004, 2007). However, when it comes to the detection of relevant change processes, it is frequently those (‘irrelevant’) phenological responses, which are superimposed on the ‘true’ signal of change. Currently the only way to correct for this “noise” in the phenological response of the vegetation is the interpretation of the detected changes with rainfall data. But even this approach has its shortcomings as we are not able to accurately distinguish, for example, between bush encroachment and rainfall-related vegetation increase when comparing a drier year with a wetter year in a multispectral image series.

From the perspective of remote sensing, research needs to explore the use of spatially and spectrally higher resolved data. The analysis of (mainly greyscale) historical aerial photos can be useful, too, as the high spatial resolution principally allows for the identification of single tree and shrub canopies. However, the technical challenges of aerial photo processing and normalisation currently impede the application of such an approach for large areas.

For the future, monitoring systems based on high resolution multispectral satellite sensors such as Quickbird, RapidEye, and aerial multispectral and hyperspectral data could be developed. The identification of single tree and bush canopies or the distinction of characteristic spectral signatures of vegetation species should allow for the distinction between grasses and woody species. Another option is the further exploration of radar and Lidar sensors, which allow for the assessment of structural landcover characteristics, which overcomes the limitations of spectral approaches.

Several BIOTA teams tried to assess bush encroachment using field observations, field experiments and different remote sensing approaches (see e.g. Subchapter IV.2.7 as well as Articles III.2.3 or III.2.4). However, the data and image time series analysed during the last nine years still do not provide a clear picture of possible long term trends for larger regions. The analysis of long term rainfall data, however, shows a periodicity of about 10–11 years for Namibia of dry and wet spells (Engert & Jury 1997).

In order to determine the long-term trend in vegetation composition a data series of at least several decades would be necessary. Even if we have access to some valuable historical rainfall records from some farms in the region, the currently available satellite archives of about 30 years are still insufficient to establish significant long-term trends. Even worse is the situation with regard to vegetation monitoring data, as most regions were only surveyed for the first time during the BIOTA project. In the absence of any historical survey data, the regular surveys conducted during the BIOTA period have provided an important first step in the development of a long term monitoring data base.

Finally, the project also contributed significantly to our understanding of savanna dynamics and the factors, which drive them. It pointed us towards many challenges in savanna research that still need to be resolved and will helped us to formulate the appropriate research questions for projects to come.

2.3 Eco-hydrology of Thornbush Savanna

Introduction

As shown in the previous subchapter, vegetation dynamics is largely driven by the variability of precipitation. However, the amount of rainfall that becomes available to the vegetation as soil moisture also depends on the soil structure and type, the topography of the landscape and the vegetation cover itself. Vegetation cover and composition strongly influence rainfall interception, infiltration, run-off, and water losses through evapotranspiration. Understanding the complex interaction of soil, topography, vegetation, and soil moisture is an interdisciplinary key challenge for empiricists and modellers. In the following, we present a field study on the small-scale factors controlling local soil water budget and a set of modelling studies that explore the dynamic interaction of savanna vegetation and soil moisture driven by current and predicted future climate.

Empirical findings: soil water balance at savanna sites

[N. Classen, A. Gröngröft & A. Eschenbach]

On the Farm Otjiamongombe (Erichsfelde), about 110 km north of Windhoek in the central Namibian Thornbush Savanna, four typical sites were selected and detailed studies of in-situ water balances conducted in the years 2007 to 2010. The studies aimed at a quantification of controlling factors for the local soil water budget, especially with regard to the varying soil properties, the patchy vegetation, and the occurrence of physical or biological surface crusts. Here, for one site and season, the results will be summarised and some general conclusions drawn.

Methods. On each site, along a 30 m transect, soil water probes were installed at characteristic surface situations (e.g. canopy of small *Acacia* trees, *Stipagrostis* tussocks, open soil patches). Addi-

Photos 1 and 2: Study site at the Farm Otjiamongombe (Erichsfelde), general view of the site (left) and soil profile (right).

tionally, at two positions (*Acacia* canopy – open grassy) sensors were installed in the soils at four depths (20, 40, 60, and 80 cm) and connected to loggers for automatic reading. The device consisted of i) sensors for measuring soil water content and temperature (Easytest, Institute of Agrophysics, Lublin, Poland), ii) gypsum probes for the measurement of water tension (Watermark, Irrometer company, Riverside, USA), limited to tensions up to 0.2 Mpa), and iii) climate sensors for the reading of precipitation (Raingauge, Mike Cotton Systems, South Africa), and air temperature (Handylog, Driesen & Kern, Germany). To determine the soil water content in the areas between the sensors the readings were interpolated and the layer above the upper sensor was regarded as of constant moisture. In case of data loss (e.g. by termite destruction of sensor cable), the water retention curves were used to calculate missing values.

Results. In Fig. 4, the precipitation and the course of soil water pressure is depicted for two neighbouring positions on one site and the rainy season 2008/2009. Soil at this site was classified as a Haplic Luvisol (see Table 1). The vegetation is dominated by patches of *Acacias* (*A. mellifera* and *A. tortilis* with a height up to 5 m) and of dwarfshrubs (*Monechma genistifolium*) (Photos 1 & 2). Protected through the *Acacia* canopies, a dense layer with single grasses is developed, which forms dense stands at the end of the rainy season. The both profiles have a distance of 10 m.

The data indicate:

- The rainy season was split into two distinct phases: a) the first rain events from the end of November until Mid of December (in total 105 mm on 32 days) and b) a phase from mid of January to begin of March (in total 445 mm on 48 days). While the distribution was typical for the region, the total amount of 558 mm was significantly above the annual average of 396 mm.
- At a depth of 20 cm, the first decrease of soil water tension took place ten days directly after the first rain of 14 mm. This was only true for the grassy site. Below the *Acacia* canopy, even after the sum of 332 mm (227 mm since January) rain the water tension stayed constantly high.
- A comparison of the water tension between grassy and *Acacia* sites shows significant difference: The soil below the *Acacia* canopy got wet substantially later and dried out earlier.
- For the days without rain and with dry subsoil, the change in water storage could be used to estimate the daily evapotranspiration (ET). For the whole period, ET was summed up to about 375 mm.
- Taking rain (P), ET, I and change in water storage (ΔR) into account, the resulting water balance shows a seasonal surplus of ca. 150 mm.

Table 1: Characteristics of the soil on a Thornbush Savanna site on the Farm Otjiamongombe, about 110 km north of Windhoek, central Namibia

Soil classification (WRB)	**Haplic Luvisol, hypereuric**
Texture	sandy loam to sandy clay loam
pH-Value [in $CaCl_2$]	5.5–6
EC $_{2,5}$ [µS/cm]	11–22
C_{org} in topsoil [%]	0.350

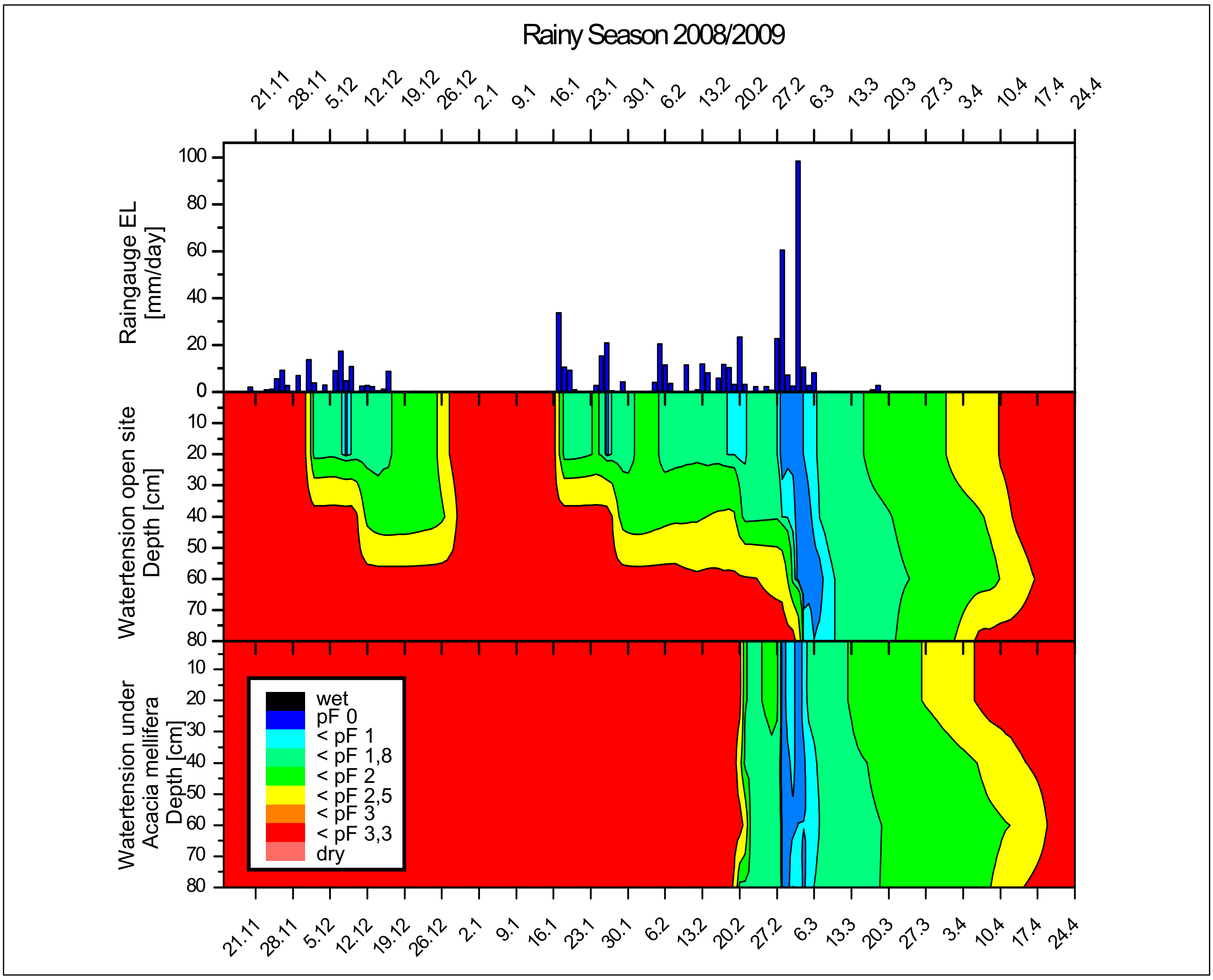

Fig. 4: Precipitation and water tension at two profiles on loamy soil in Thornbush Savanna. The two profiles are at an open (i.e. grassy site) and an *Acacia* woodland site.

- At the end of the rainy season strong rain events led to subsoil wetting for both sites. At this time, deep drainage was possible. There were no signs of water saturation above the bedrock in this period.
- To maintain the transpirational demand of the vegetation, water storage was needed for 5 weeks after the end of the rainy season.

Conclusions.

- The local water budgets are substantially altered by the vegetation structure and distribution. Here, tree stands lead to canopy interception and thus reduced water infiltration.
- In seasons with sufficient rainfall, it is possible for the deep-draining water to reach the saprolite and the underlying fissures in the bedrock although this was not recorded in this study. Most likely, part of this water is used by deep rooting trees and thus improves biomass production. It is impossible to quantify this amount of water storage with conventional soil hydrological measurement devices.
- To fulfil the water balance, additional water losses through runoff have to be regarded.

To understand the competition between grasses and trees in mixed savanna sites and thus the drivers of bush encroachment it is necessary to study the hydrological interaction between soils and vegetation in more detail. Especially, the transpirational demand of the grass and tree species under varying soil moisture stress conditions and the redistribution of soil water by some Acacia trees have to be quantified in future. In Namibian soils, which are characterised by a restricted fine earth cover overlying saprolites and bedrock, the role of the geologic substratum has to be taken into account. Here, the application of sap flow meters, which have been successfully tested on the study site in 2009, promises to be a valuable tool to understand water relations of woody plants in areas with a strongly restricted water supply.

Eco-hydrological modelling and scenario analyses

[F. Jeltsch, M. Wieczorek, S. Meyfarth, N. Blaum, E. Rossmanith, D. Lohmann, A. Popp & B. Tietjen]

Drylands are characterised by a tight coupling of water availability and vegetation dynamics and the risk of deterioration is high due to the extremely variable climatic conditions. Deterioration, often linked to rangeland overexploitation in combination with unfavourable climatic periods, can either take place in the form of increasing bare patches of soil associated with increasing erosion risks (Kefi et al. 2007) or the fragile equilibrium between woody and herbaceous vegetation can shift towards a shrub-dominated state (Roques et al. 2001). Climate change in drylands is likely to increase these risks of degradation with predictions of decreasing mean annual precipitation (Dore 2005), increasing temperatures and increasing number of extreme events (Easterling et al. 2000, Solomon et al. 2007).

While recent meta-analyses show the principle relationship that exists between woody cover and rainfall in arid and semi-arid savannas with a mean annual precipitation below 650 mm (Sankaran et al. 2005) this relationship cannot easily be extrapolated to the transient dynamics that are to be expected under future climate change conditions. Feedbacks between vegetation cover and soil moisture through infiltration, evapotranspiration, and runoff modification, as well as changes in plant-plant interactions, are likely to lead to complex, non-linear vegetation changes. Computer models, which simulate the key eco-hydrological processes can help to better understand these complex feedbacks and assess risks caused by different climate change scenarios. Fig. 5 shows the principle structure of eco-hydrological models developed and applied in the BIOTA Africa framework.

Table 2: Water balance for the 2008/2009 season (15.11.08–22.4.09, Acacia site)

Variable or measurement	Amount (mm)
Precipitation (P)	558,6
Maximum soil water storage (0–80 cm depth)	110,8
Change in water storage (ΔR)	6,8
Evapotranspiration (ET) estimated	374,2
Interception (I) estimated	29,1
Surplus (P-ET-ΔR-I)	148,5

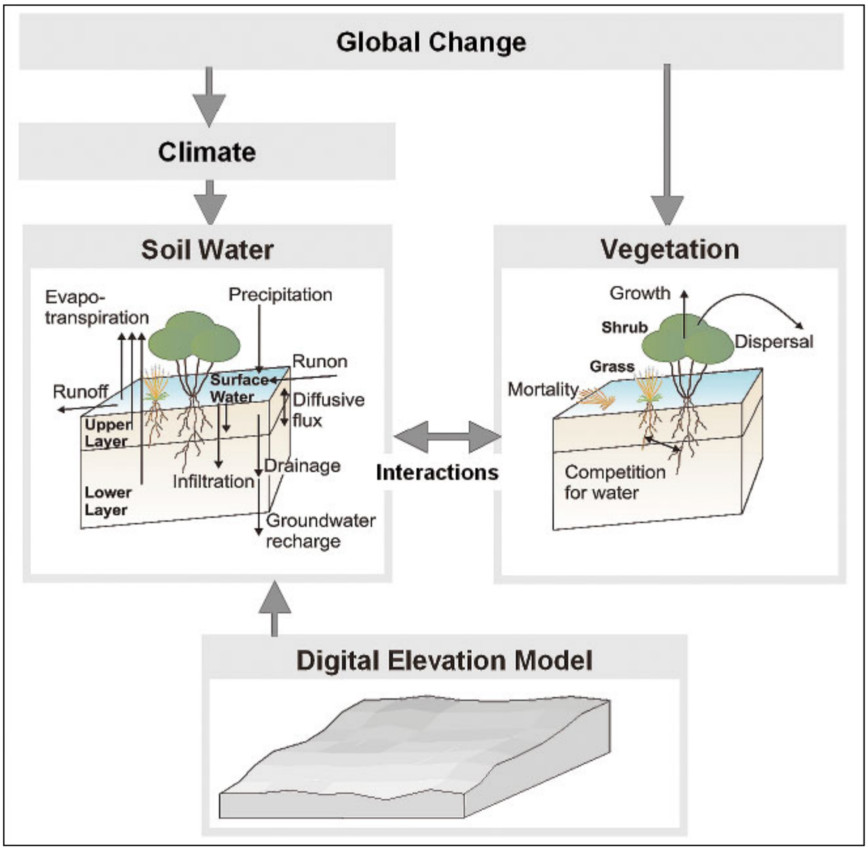

Fig. 5: Schematic description of the eco-hydrological model EcoHyd (Eco-Hydrology in Drylands; Tietjen et al. 2009a, b) dynamically linking vegetation and soil moisture in realistic landscapes under scenarios of climate change. The model accounts for the intensity and duration of single precipitation events and the resulting dynamics of different woody and non-woody plant life forms. The water component of the model simulates the daily dynamics of surface water and water contents in two soil layers. The vegetation elements compete for this soil water and strongly influence hydrological processes.

A key challenge in this eco-hydrological framework is the assessment of the role of different soil types in modifying the effect of climatic changes on vegetation. Using examples of a rainfall gradient in Namibia we compared two Thornbush Savanna sites (Sonop, approx. 495 mm/ year, and Otjiamongombe, approx. 360 mm/ year with an even drier site in the Nama Karoo (Gellap Ost, approx. 150 mm/year) [Note: information on mean annual precipitation (MAP) used for modelling were derived from the Atlas of Namibia, http://www.met.gov.na/programmes/infocom/infocom/atlas.htm]. In a first step, computer simulations were conducted with constant site-specific vegetation cover and an identical topography for the three test sites but with variable rainfall conditions to focus on the effects of soil type and precipitation pattern. With regard to the latter, we tested a rainfall time series with an unchanged mean value and a series with a 10% reduction of mean annual precipitation. Further, for both of these variants, we tested the effect of an increase of extreme events, i.e. a reduction of low rainfall events and an increase of the amount of rain falling during high rainfall events without changing the annual mean. As an output measure we used the relative change in number of growth days per rainy season, i.e. the number of days where soil moisture was sufficient for

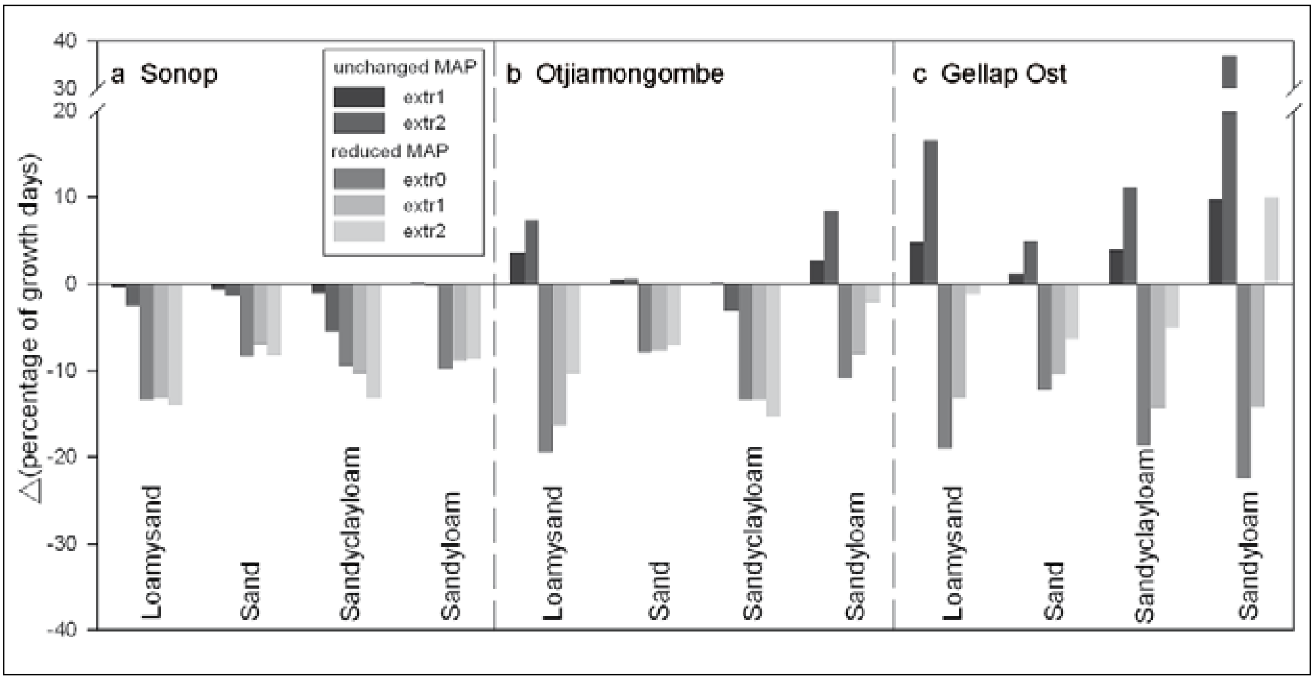

Fig. 6: Effect of different rainfall change scenarios on the number of plant growth days for different soil types at three sites along a rainfall gradient in Namibia (Sonop: approx. 495 mm/year, Otjiamongombe: approx. 360 mm/year, Gellap Ost: approx. 150 mm/year). The columns give the relative difference in number of growth days compared to the unchanged, site-specific rainfall conditions. The left two columns for each soil type are the unchanged MAP scenario but with an increasing shift towards more extreme rainfall events (extr1-2). The three columns on the right for each soil type reflect a 10% reduction in MAP (extr0), plus an increasing shift towards more extreme rainfall events (extr1-2).

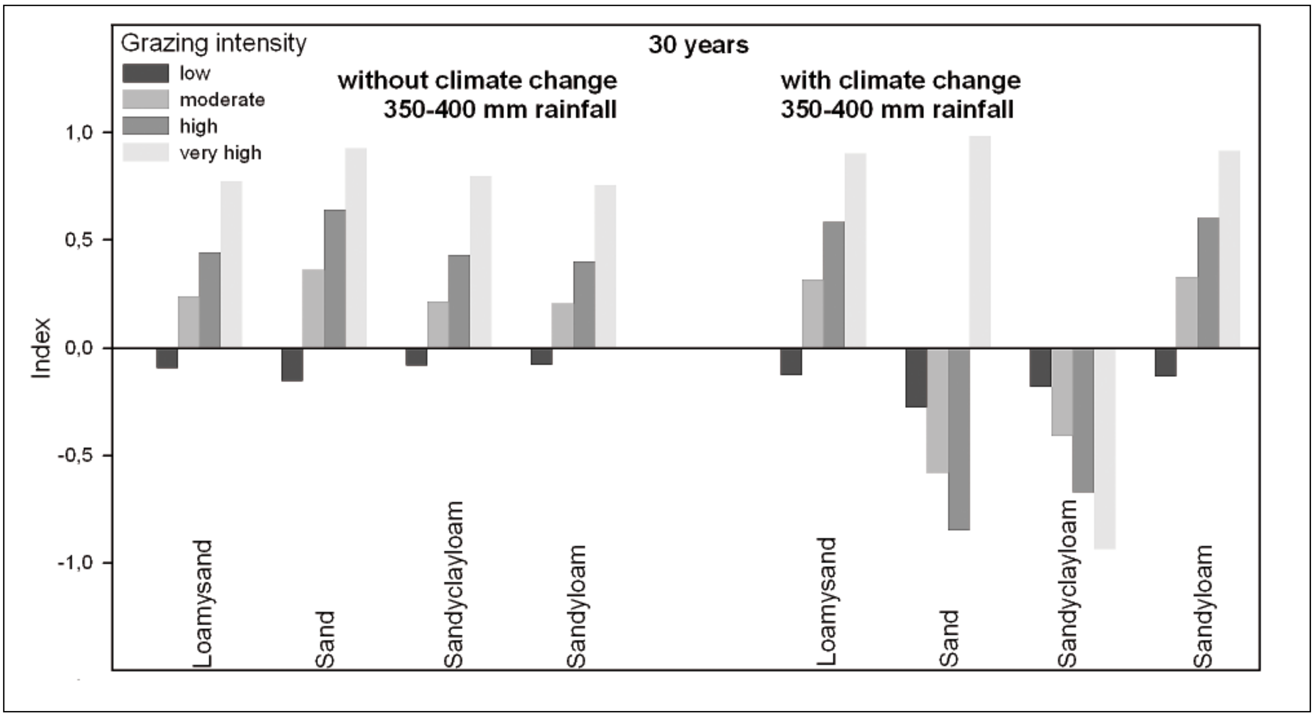

Fig. 7: Simulated vegetation degradation index *deg* (compare Article III.7.2) after 30 years of light, moderate, heavy and very heavy grazing (from left to right) for four different soil types. Left: current climatic conditions for the 'Otjiamongombe' savanna region in Namibia with an average annual rainfall from 350 to 400 mm. Right: climate change scenario without consideration of possible effects caused by CO_2 increases. Note: The absolute value of the index *deg* resembles the relative loss of cover of perennial grasses under different levels of grazing intensity as compared to a situation without grazing. In addition, negative values indicate that the absolute value of shrub cover and the mean increase of shrub cover within the given time frame is less than 5%.This suggests that the risk of soil erosion is more prominent than shrub encroachment, at least if index values are high (otherwise values are positive). Low index values in general indicate a small loss of perennial grass cover and thus a low risk of degradation.

plant growth. Fig. 6 shows that the three test regions show different responses to modified rainfall. As expected, all sites show a strong reduction in growth days with a 10% reduction in annual rainfall. Also, for all sites the specific soil type has a strong influence on the change in growth days. However, while the increase in extreme events has a positive effect for the drier sites it has no or only slightly negative effects for the most mesic site. For the drier sites this finding clearly corresponds to the increased precipitation evident during high rainfall events, which leads, in turn, to soil moisture conditions above a threshold that allows for plant growth. The reduction of low rainfall events has little negative effect since these events are not sufficient to significantly increase the growth period. This is different for the more mesic site, where even the lower rainfall events facilitate plant growth. The reduction of these events at the more mesic site, however, is not fully compensated for by the increase in precipitation of high rainfall events. Again, the specific results for a given site are influenced by the soil type.

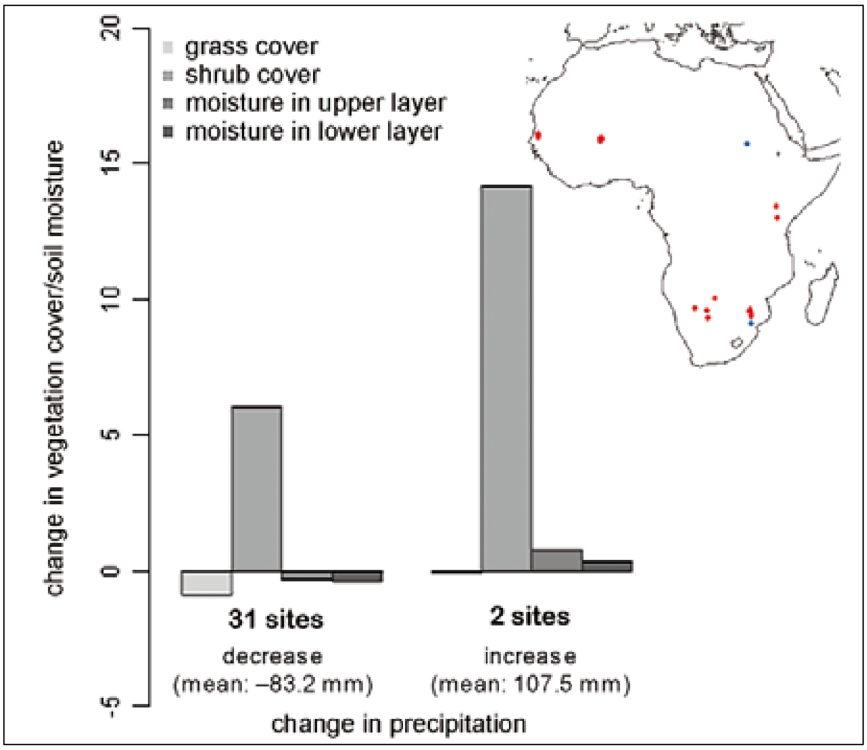

Fig. 8: Simulated combined effects of climate change (based on site specific scenarios of climate change and landuse) and an increase of atmospheric CO_2 on vegetation cover and average soil moisture levels in 33 different arid to semi-arid Thornbush Savanna sites in Africa (see map). Left: mean changes for sites with a predicted decrease in mean annual precipitation (map: red points). Right: sites with a predicted increase in mean annual precipitation (map: blue points). All scenarios are based on IPCC (Solomon et al. 2007) and Sankaran et al. (2005).

Using the example of the 'Otjiamongombe' Thornbush Savanna region with an average rainfall of approximately 360 mm, we next included dynamic vegetation responses (i.e. dynamic vegetation changes as a result of plant-soil moisture interactions) and livestock grazing. Again, model simulations clearly indicate the high relevance of the soil type for climate change effects. Comparing the effect of different grazing intensities on vegetation shows that under current climate conditions different soil types only lead to minor differences in vegetation degradation (Fig. 7). However, under a reasonable scenario of climate change (i.e. 10% reduction of mean annual precipitation and a temperature increase of 2.25°C) simulations show a generally higher risk of losses of perennial herbaceous vegetation cover (i.e. higher absolute values of the index *deg*). Model results further indicate that for two of the four soil categories shrub encroachment accompanying the loss of grass cover gets less important for all but the highest grazing intensity (negative values of the index *deg*). As a consequence, the total cover of perennial vegetation is reduced and the risk of soil erosion further increases. Risk assessment maps for the focal Thornbush Savanna region in Namibia under climate change that are based on the described simulation approach and degradation index are given below in Subchapter IV.4.5.

Results of climate change impacts on vegetation presented so far were based on modified rainfall and temperature conditions. A further factor that is assumed to impact vegetation changes (also in savannas) is the increasing level of atmospheric CO_2. Increased atmospheric CO_2 could mitigate the described climate change effects directly through the higher photosynthetic rates of plants, which occur under such conditions, and indirectly by enhancing the water use efficiency (Drake et al. 1997). However, the effects of elevated atmospheric CO_2 can vary strongly between plant types (Ainsworth & Long 2005). The growth rate of juvenile woody species with a high carbon demand could be especially sensitive to an increased CO_2 level, which could alter the shrub-grass balance (Bond et al. 2003, Tietjen et al. 2009b).

While effects of altered precipitation levels and temperature on savanna vegetation are relatively well understood the impact of elevated CO_2 generally remains more speculative. Interestingly, including increased growth rates for woody vegetation and enhanced water use efficiency for all vegetation in the described eco-hydrological models leads to a change in the general vegetation response pattern to climate change. Climatic changes alone typically lead to a general loss of perennial vegetation cover and a reduced risk of shrub encroachment. In contrast, the combination of climate change with CO_2 effects leads to an increase in the risk of shrub encroachment for 33 simulated Thornbush Savanna sites across Africa (Fig. 8). This holds both for sites with a predicted decrease and for sites with a predicted increase in mean annual precipitation. These results clearly show that as long as the effect of increasing CO_2 levels on the complex vegetation-water dynamics are not fully understood any predictions on climate change effects in drylands savannas need to be interpreted with caution.

2.4 Vegetation patterns and biodiversity dynamics

Key vegetation patterns in Thornbush Savanna rangelands

Impacts of rainfall on vegetation cover for two major savanna topsoils in Namibia

[M. Strohbach]

Botanical surveys throughout the Namibian Thornbush Savanna (sensu Giess 1998) revealed a tendency of these landscapes to develop bare patches, ranging from two to four meters to several hundreds of meters in diameter. This problem is most severe on the Etjo Erosion plains. The origins of such bare patches appear to be a combination of natural, erosion related processes, coupled with inappropriate grazing practices. Developing mosaic systems are relatively common in savanna vegetation, but are widely regarded as a form of degradation of a previous continuous vegetation cover (Valentin et al. 1999), which may become more difficult to reverse as rainfall patterns (and other climatic variables) continue to change.

The herbaceous vegetation (i.e. the grass and forb layer) is the most affected by landuse practices as well as the highly variable rainfall experienced in the area. Hence, cover values of this layer show the most dramatic inter-annual fluctuations, making the accurate detection of actual degradation difficult (Wessels et al. 2007, Vogel 2006). To better understand and interpret inter-annual changes in the herbaceous layer, the cover of all these species were documented, together with daily rainfall over a period of four years, at permanent sites on a farm on the western Etjo Erosion plains (21°06’ S and 16°36’ E, mean annual rainfall: 366 mm).

In this study, the herbaceous vegetation was divided into non-grassy forbs (hl), perennial grasses (gp) and annual grasses (ag). Each of these groups was further divided into grazing response groups, namely Decreaser species (D), Increaser species (IN) and Other, the latter being species whose cover is primarily influenced by rainfall. The change in canopy cover and species number of the herbaceous vegetation growing on different topsoils (on which especially grass species differ due to their ecological preferences) was compared over four years (2005–2008) (Fig. 9).

The sites with loamy sand were grazed by between 30 and 50 medium-frame cattle, rotated on an ad-hoc manner between four camps. During 2006 this was increased to 80 oxen due to the above-average rainfall that season. The sites with sandy loam were grazed by a herd of 100 to 150 Dorper sheep and occasionally a small group of milking cows with their calves (less than ten animals), rotated between four camps, spending a maximum of three weeks in a camp. From June 2006 onwards, the single camp in which the monitoring sites were located was stocked with about 650 Damara sheep, increasing to about 800 when lambs arrived, and rotation was slowed down to about 2.5 month periods per camp. The rainfall recorded during the study ranged from well below to well above average (Fig. 9). The drought during 2006/2007 resulted in the large-scale sale of animals and the flooding of markets country-wide. Because of this, farmers were unable to sell their livestock, and the camps with the monitoring sites could only be de-stocked in December 2007. The camps were left without livestock during 2008.

The results show that on the sites where the topsoil was comprised of loamy sand, perennial grasses were not as severely affected by overgrazing during 2007, as sites with sandy loam and managed to recover to some degree during 2008 (Fig. 9). There was also an almost complete absence of all annual species during the 2007 drought. The sites (and camps) with the sandy loam topsoils, which generally have a lower vegetation cover and often show vast expanses of bare patches, showed a very poor recovery of perennial grasses after the 2006 and 2007 overstocking, despite adequate rains and no livestock present during 2008. Perennial grasses were instead replaced by a high amount of short-lived annual grasses and an invasive and highly unpalatable forb, *Ondetia linearis*.

Important for management decisions, is the suggestion that palatable, perennial grasses appear to be more abundant and more resilient where topsoils are relatively sandy. It can also be clearly shown that the recovery of perennial grasses, if grazed excessively during a drought period, is not nearly as rapid (within one season), as many farmers would hope, even with sufficient rainfall. This is most evident on the loamier (and hydrologically less favourable) soils. This would imply that erosion of sandy topsoils should be prevented as far as possible, whilst also showing the importance of either reducing stocking rates rapidly during years of drought, or in some way trying to avoid extensive grazing in camps with a high cover of palatable grasses. Most important, however, is the view that long-term stocking rates for an area need to be determined according to average grazing availability during the dormant season, and not during the peak growing season, as is still standard practice with most farmers and agricultural authorities.

The role of mound building termites for the soil structure and nutrient patterns

[C. Grohmann, A. Petersen, T.V. Medinski, A. Mills, A. Gröngröft & K.E. Linsenmair]

Most parts of the Namibian Thornbush Savanna are peppered with termite mounds built by the fungus growing species *Macrotermes michaelseni*. The mounds often occur in high densities. For example, more than four inhabited and uninhabited mounds per hectare were found on the Observatory S04 (Toggekry) (Grohmann et al. 2010). Via the construction of their mounds and the processes within their mounds, termites significantly influence the soil properties and therewith many ecological processes in their habitats. In general, termites modify soil structure and nutrient patterns through at least two processes: i) the allocation of soil material for the construction of mounds and sheetings

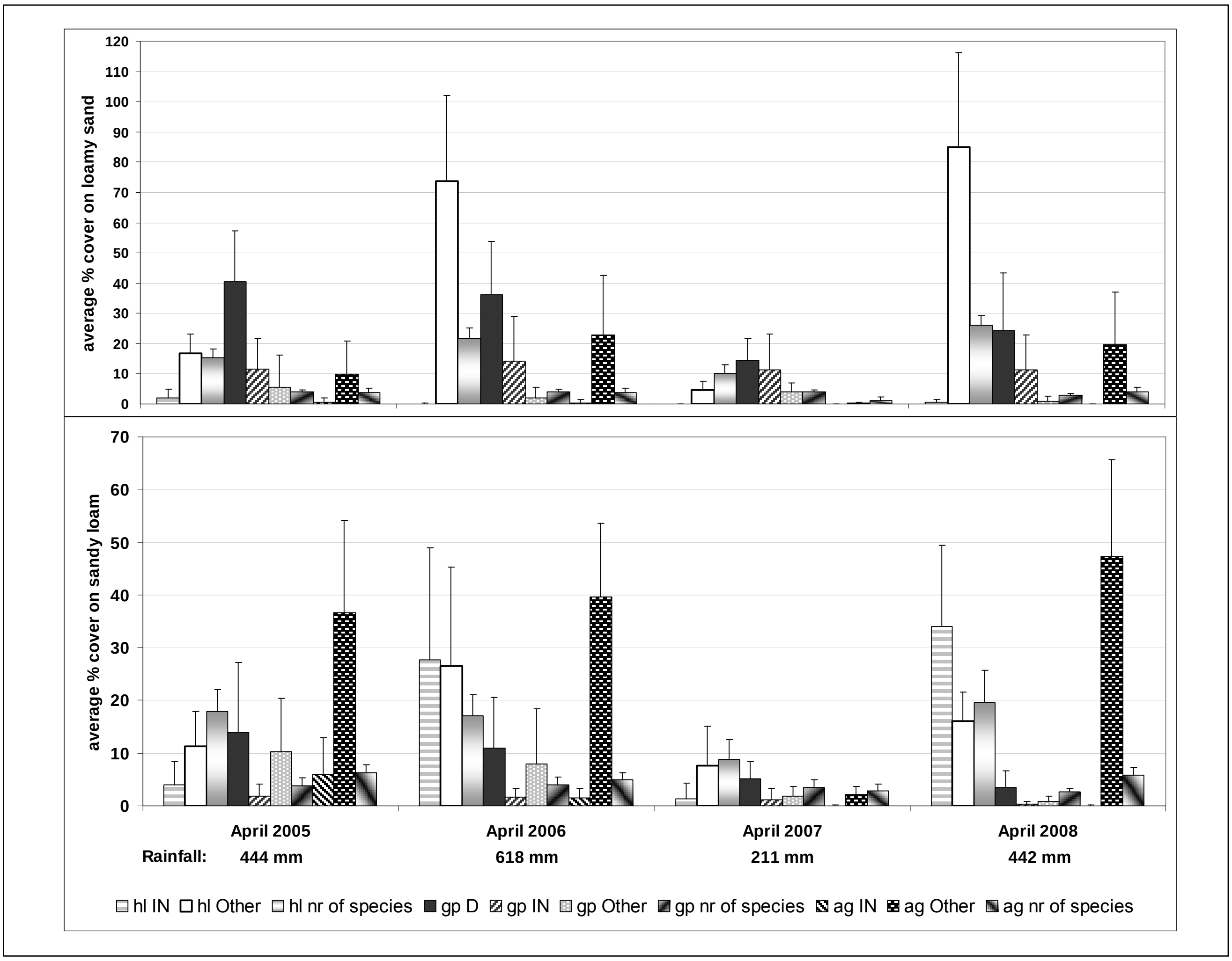

Fig. 9: The change in average canopy cover and species richness (2005–2008) within three groups of herbaceous plants and three grazing response groups growing on loamy sand (top) and sandy loam (bottom) soils on a farm on the western Etjo Erosion plains, Namibia. The three groups of herbaceous plant are (hl) non-grassy forbs, (gp) perennial grasses and (ag) annual grasses while the three grazing response groups are (D) Decreaser species, (IN) Increaser species and (Other) (see text for further details). The rainfall figures reflect annual values for the period May–April of each year. Note the difference in scale of the y-axis in the two graphs.

(soil constructions, which the termites build to protect themselves when they forage) and ii) the transfer of organic material to the fungus gardens and its subsequent mineralisation.

These termite-mediated changes of soil properties have subsequent impacts on plant biomass and vegetation composition. For example, Rogers et al. (1999) found suppressed plant growth on termite mounds, which they attributed to the impenetrability of the mound surface for the roots of the seedling plants. In some regions, mound soils are used as manure (e.g. Nyamapfene 1986). *Macrotermes* mound material is also frequently ingested by wild animals and humans (geophagy), possibly for its nutritional value. Mills et al. (2009) speculated that mound earths could provide a critical supply of especially scarce nutrients such as selenium, to wildlife and humans alike. They likened the mounds to ‘nutrient fountains’ within the savannas of Africa and parts of Asia.

The main question of this study was how the structure and nutrient patterns differ between mound-soils of the fungus growing termite, *M. michaelseni*, and the surrounding soils.

For this study, on the BIOTA Observatory S04 (Toggekry) soil samples were taken from the chimneys of 26 inhabited mounds and 26 topsoils (0–10 cm in depth) next to each mound. The total contents of N, K, Ca, Mg, P, and S of the soils were analysed and the logarithms of these values were used for the statistical analyses. Additional samples were taken from this Observatory as well as from the BIOTA Observatories S05 (Otjiamongombe), S03 (Sonop) and the research farm Omatjenne. These samples were analysed with respect to the exchangeable cations of Ca, Na and Mg, the EC and pH contents, as well as their texture (grain size).

The results show, that the mound soils could clearly be differentiated from their nearby soils with respect to their total N, K, Ca, Mg, P, and S contents (Fig. 10). The difference between the mound soils and the adjacent soils was significant (ANOSIM, $p < 0.001$). Most of the macronutrients (total N, Ca, Mg and S) were enriched in the mounds (Wilcoxon signed rank test, $p < 0.001$). However, P showed

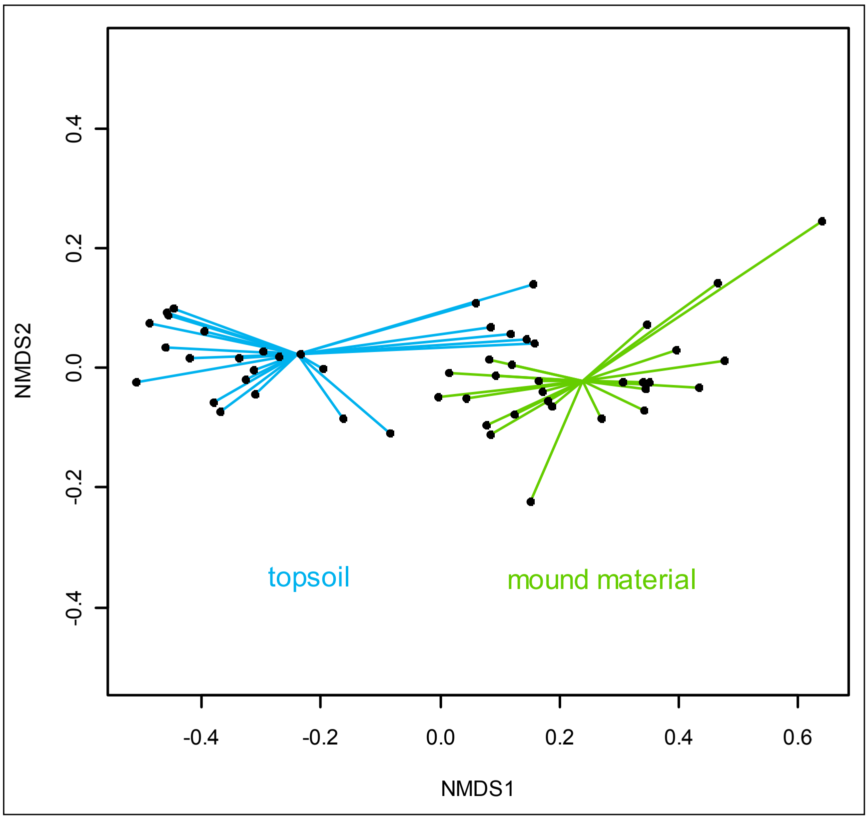

Fig. 10: NMDS-plot of soils from 26 inhabited termite mounds (connected to their group centroid by green lines) and 26 nearby relatively unmodified soils (connected by blue lines), using Euclidean distances. The ordinations arrange the soils (black dots) so that soils, which have similar values of total N, K, Ca, Mg, P, and S contents, are closer to each other compared with dissimilar soils. The plot was rotated so that the variance of sites is maximised on the first dimension. Soil nutrients were added to the plot. Stress: 2.99.

no significant pattern, and K was less concentrated in the mound soils compared to the surrounding soils (Wilcoxon signed rank test, $p < 0.05$). Similar results could be found when analysing the additional samples. Here, higher values of exchangeable Ca, Na and Mg, EC, pH, clay and fine silt contents were found in mounds soils compared to surrounding topsoil.

The enrichment of nutrients within the mound soils is partly caused by the utilisation of subsoil for the building of the mounds and partly by decomposition processes within the fungus gardens of the mounds. The high values of Ca, Mg, and Na can be attributed to the selection of clay-rich subsoil for the mound construction. This clay-rich subsoil exhibits high content of total Ca, Mg and trace elements (Petersen 2008, Mills et al. 2009). The magnitude of clay enrichment of *Macrotermes* mounds from several sites was 4.7 to 6.5 fold compared to adjacent topsoil (Mills et al. 2009).

In contrast, the main source of total N (mainly composed of nitrate) and S in the mounds can be attributed to the highly effective decomposition and mineralisation of organic material by the fungus, which is cultivated by the termites and assists in the digestion of cellulose and other plant material. Through the reconstruction activities of the termites, the N and S were probably distributed from the region of the fungus gardens to the mound chimney. Another path of distribution within the mound might be the indirect transport by water. If nitrate dissolves in water, which then is transported to the chimney, the nitrate can be fixed here by evaporation. Furthermore, at the same time, the leaching of soluble and exchangeable ions is reduced by the lower water permeability of mound walls compared to the adjacent soil (Watson 1976). Another source might be the saliva of the termites with which the soil particles are mixed before they are used in mound building (Holt & Lepage 2000).

It is often assumed that the observed high nutrient contents of the termite mounds have a greater impact on plant biomass than soils from the surrounding areas. However, on the Observatory S04 (Toggekry), the growth of radish and sorghum was reduced on soil from *Macrotermes* mounds compared to soils from the surrounding areas (Graiff 2010). This may have been due to soil water shortages as a result of the high clay contents of the termitaria, or nitrate toxicity or salinity effects. The same effect was found for radish growing on mound material of a different *Macrotermes* species in a study conducted in the framework of BIOTA West in Burkina Faso (Siegle 2008). However, the biomass of herbs and grass growing on termite mounds was much higher compared to the surrounding soil in a year with extraordinary high rainfall, in which the termite mound soils were soaked thoroughly (Graiff 2010). This enhanced growth may have been linked to the greater availability of water in that year as in years with average rainfall, rainwater hardly infiltrates the mound but is mostly lost through run-off processes from the surface of the mound. Other explanations might be reduced nitrate toxicity and salinity effects as a result of soil leaching.

In conclusion these results show that mound-building termites have a strong impact on soil structure and nutrient patterns within the savanna ecosystem. Firstly, through the constant turnover of soil, evident in the massive mounds comprised of nutrient-rich subsoil and by the redistribution of this material via wind and rain, a “rejuvenation” of the soils takes place. In this way, the consequences of the leaching of nutrients from the topsoil to deeper soil layers are reduced by termites through the redistribution of nutrients to the topsoil. Secondly, termites are the main decomposers in arid savannas (Buxton 1981), and play a key role in the humification and mineralisation of plant material.

In addition, termites also influence the water supply of the soils directly, which should be analysed in more detail in the future. The complex underground galleries, which they build to reach their food sources, are important for the vertical and lateral distribution of water in the soils.

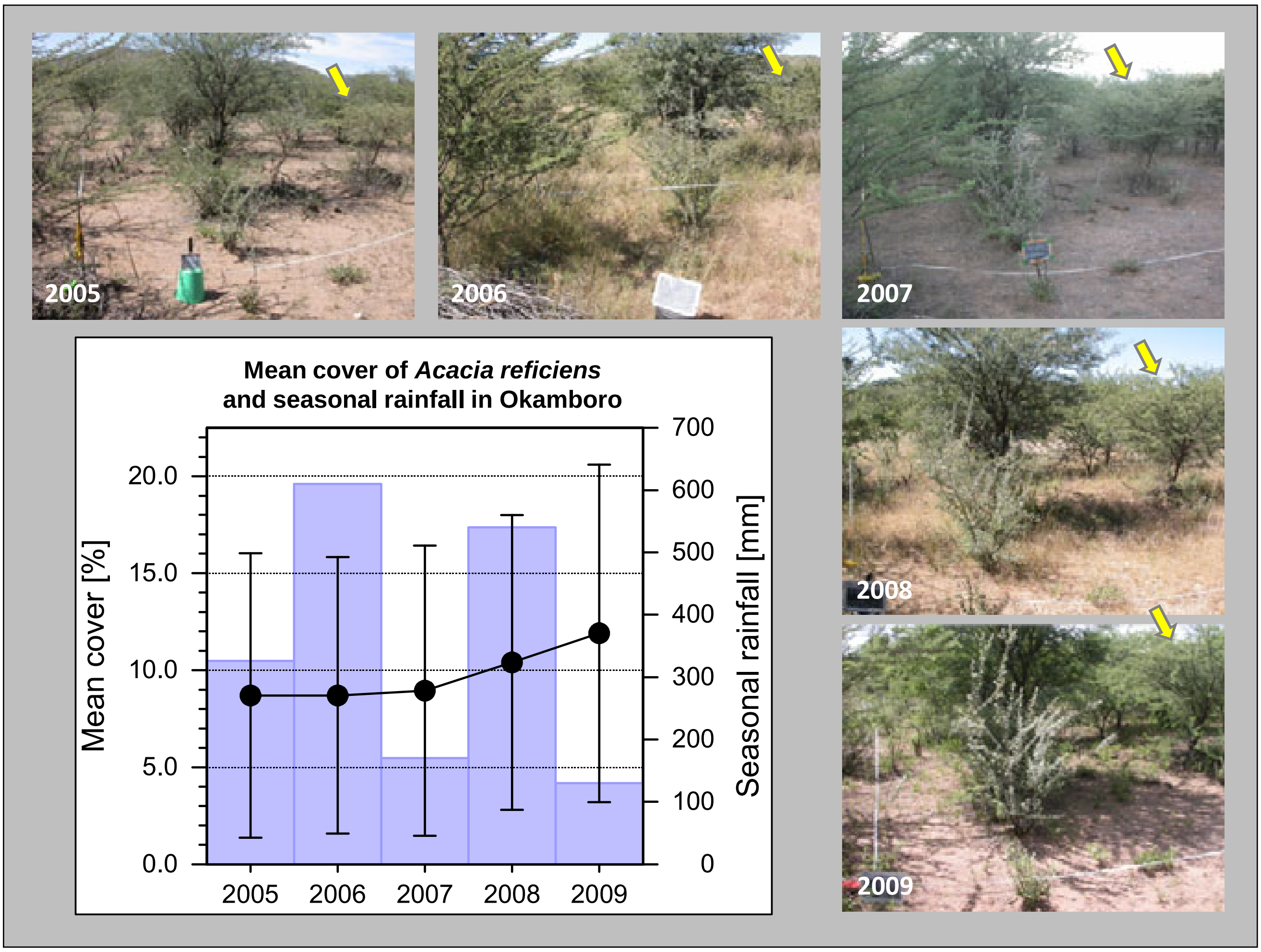

Fig. 11: Mean cover (±std. dev.) of the encroacher species *Acacia reficiens* on 20 permanent monitoring plots (each 1000 m²) of the BIOTA Observatory Okamboro (or Ovitoto, S06) over the period 2005–2009. The fixed point photographs, taken every year in the growing season are used for illustrative purposes to show the changes in vegetation cover and composition over the five-year period within one sampling plot (hectare number 86). Arrows point to the same individual of *A. reficiens* in the respective year.

In particular, it is the openings of the galleries on the soil surface that appear to enhance several fold the infiltration of rainwater into the soil (Léonard & Rajot 2001, Kaiser et al. 2009).

Finally, climate change will have considerable impacts on ecosystems in the future and will affect termites through several key mechanisms. The predicted increase in temperature for central Namibia will affect, for example, the temperature-sensitive system of the fungus garden cultivated by Macrotermitinae. In this context, changes in vegetation composition (e.g. wood to grass ratio) will also affect termite communities and their role in ecosystems. Experiments on the temperature plasticity of the fungi and the required food composition of different termite species will thus be valuable in predicting at least some of the likely consequences of temperature changes on ecosystem functioning.

Snapshots of grazing induced bush encroachment in the central highland of Namibia

[D. Wesuls]

Although bush encroachment due to overgrazing is widespread in Namibian Thornbush Savannas and is considered as a major form of land degradation (de Klerk 2004), the speed at which encroacher species can grow has been rarely documented. One important bush encroacher species in the central Highland of Namibia is *Acacia reficiens* (Red Thorn). An excellent study system to monitor bush encroachment is the Ovitoto area (22.02°S, 17.06°E), situated in the central Highland of Namibia where landuse has changed rapidly during the last decade. The area of the BIOTA Observatory Okamboro (S06) in the Ovitoto area was a former part of a military base and is now used as a communal rangeland. Since 2001 new settlements have been built close to the Observatory leading to an intensified landuse and, as a consequence thereof, the number of free ranging cattle increased.

In 2005, 20 permanent study plots of 1,000 m² each were established on the BIOTA Observatory to monitor annual changes in vegetation cover and species composition in response to rainfall in this communal rangeland area. Own observations and the inspection of repeated photographs of the monitoring plots (Fig. 11) prove that of the woody species, *Acacia reficiens* in particular has shown a rapid growth response to good rainfall seasons, which were above average in 2006 and 2008.

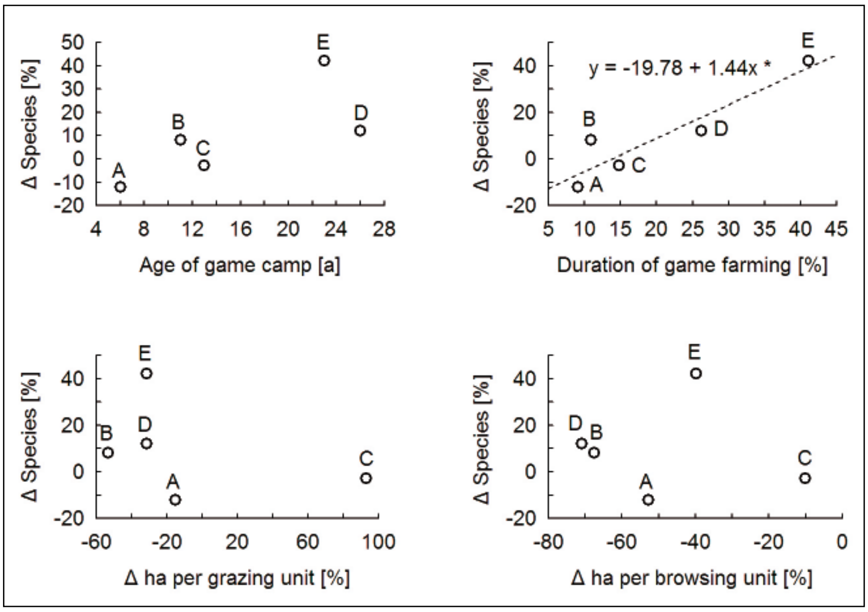

Fig. 12: Positive change of the number of plant species on game farms in comparison to adjacent sheep camps at five different sites (A–E). Grazing and browsing units have been calculated according to Bothma et al. (2004). Spearman Rank Order correlation: * = *p* < 0,05.

In general, the monitoring results showed an increase of *A. reficiens* cover by 4% over the period 2005–2009. However, because of the relatively short period of observation the increase in cover was not significant. For a semi-arid rangeland like the Ovitoto area with a high degree of variability in interannual rainfall amounts, longer periods of vegetation monitoring will be necessary to document significant changes in woody cover. Nevertheless, the observed trend indicates that *A. reficiens* has the potential to become dominant within a few years. Once young individuals have established themselves and developed an extensive root system they can grow rapidly and make rangelands inaccessible for livestock within a short period. The monitoring of individual encroacher species such as *A. reficiens* under different treatments will give more detailed information on the potential growth rates of this species independent of landuse intensity and rainfall amounts. These results would be the basis for the development of appropriate management strategies to prevent or combat bush encroachment in the Highland savanna of Namibia.

Changes in plant diversity in relation to duration and intensity of grazing

[A. Horn, C. Reisch & P. Poschlod]

Heavy grazing in conjunction with good rainfall years can lead to a rapid increase of bush encroachment within less than a decade (compare previous example), but many changes in plant species richness and composition occur at a slower pace. For example, degradation zones around watering points on 100 year old farms in the southern Kalahari around the Observatory Alpha (S17) were significantly more extensive than those on 50 year old farms (Horn 2008). This indicates that the composition of the present vegetation depends on the overall intensity of landuse, which has accumulated over many decades. The importance of including long-term processes was further corroborated by the slow recovery of former sheep camps now used for game farming (Horn 2008). The positive change in species richness on game camps in comparison with adjacent sheep camps increased with the age of the game camp (oldest game camp = 26 years) and was significantly correlated with the proportion of game farming to total farm age. In contrast, a reduction in stocking rate did not show a significant correlation with a positive change in the number of species (Fig. 12).

Farming also had effects on the spatial patterns of functional traits. For example the distribution of plants with dispersal syndromes adapted to wind-dispersal was significantly correlated with animal density within the landscape. In other words, there was a lower incidence of wind-dispersed species in intensively-grazed areas such as around 30 year old watering points, while the converse was also true where the incidence of wind-dispersed species was higher in areas with low animal density (Horn 2008). Curiously, wind dispersal potential was generally low, although few other vectors would naturally be available at high frequencies, since moving surface water is hardly ever present and natural animal densities are low. Animal-dispersed species can also be sensitive to changes in available dispersal vectors. For example, antelope act as an important dispersal vector for the tsamma melon, *Citrullus lanatus*. Their loss due to hunting and the erection of fences in the 1960s has had significant effects on seed dispersal as could be shown by changes evident in gene flow and population genetic differentiation (Horn 2008).

We conclude that while in the short-term the vegetation seems to be mostly influenced by rainfall, over longer time frames even mild overgrazing can have severe effects, especially in focal areas such as watering points. Furthermore, severe degradation is almost irreversible due to the harsh climate and associated low frequency of germination events, but also due to the transient nature of the seedbanks and the potential rarity of long-distance dispersal.

Identifying key patterns of animals diversity along landuse and climate gradients

Responses of animal diversity to shrub encroachment

[N. Blaum, E. Rossmanith & F. Jeltsch]

One of the most threatening forms of rangeland degradation in Thornbush Savannas of southern Africa is shrub encroachment resulting from heavy livestock grazing in conjunction with good rainfall years (e.g. Kraaij & Ward 2006). Although the economic effects of

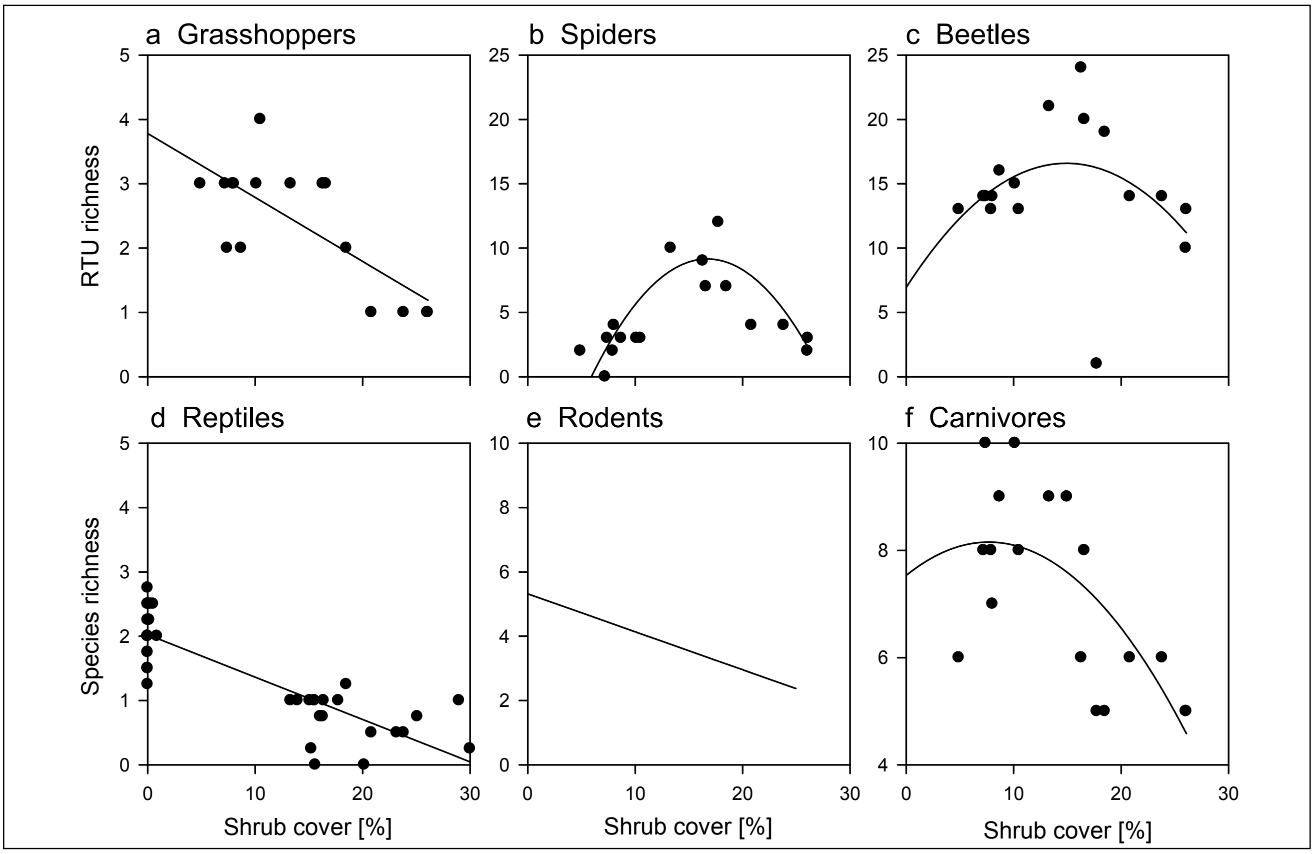

Fig. 13: Changes in animal diversity along a gradient of shrub cover (a: grasshoppers, b: spiders, c: beetles, d: reptiles, e: rodents, f: mammalian carnivores). Species richness of insects (a–c) were determined according to Scholtz & Holm (1989) and then classified as recognisable taxonomic units (RTUs; distinguished by morphological characteristics) using the rapid assessment of biodiversity approach of Oliver & Beattie (1993). Figs. 13a–c was reprinted with the permission of Springer Science and Business Media from Blaum et al. (2009b). Fig. 13e was reprinted with the permission of Blackwell Publishing Ltd from Blaum et al. (2007c). Fig. 13f was reprinted with the permission of Elsevier Ltd from Blaum et al. (2007b).

bush thickening on productive farmland are well known, the effects on savanna biodiversity are only now beginning to emerge. Assessments between habitats (Meik et al. 2002) and across experimentally-cleared plots (Kaphengst & Ward 2008) have shown declines in reptile and avian diversity between open and encroached habitat. However, only few long-term assessments across a wider landscape have been made in southern Africa for birds (Sirami et al. 2009), and within the BIOTA research framework in the Kalahari for arthropods (Blaum et al. 2009a) and mammals (Blaum et al. 2007a, b, c, 2009b).

In the BIOTA Kalahari study (i.e. the rangeland area around Observatory Alpha, S17), the impact of shrub encroachment on animal diversity (and in particular on wingless arthropods, reptiles and mammals) was studied along a gradient of shrub cover ranging from 0–30%. Carnivores were selected as potential indicators for farmers to detect changes in rangeland quality and to highlight the fact that sustainable farming is a crucial part of nature conservation. Results from the BIOTA long-term studies show that although the responses of animal groups vary between taxa two major patterns are evident. Species richness of grasshoppers, reptiles, and rodents declined with shrub cover while spiders, beetles, and carnivores exhibited bell-shaped responses to shrub cover with species richness maxima at shrub cover values between 12 and 18% (Fig. 13).

The bell-shaped responses of spiders, beetles, and carnivores to shrub cover can be explained by the habitat heterogeneity hypothesis (MacArthur & Wilson 1967), which predicts that structurally complex habitats provide more niches and environmental resources and thus increase species diversity. In southern Kalahari rangelands, the relationship between shrub cover and habitat heterogeneity (measured as the horizontal and vertical diversity of the shrubby vegetation) is bell-shaped with a maximum at 10–15% shrub cover (Blaum et al. 2007b). At low shrub cover, savannas are characterised by a structurally-poor grassy matrix with few trees or shrubs scattered in the landscape (Scholes & Walker 1993, Jeltsch et al. 1997a). The increase of shrubs therefore first enriches the structural diversity of savanna habitats (Blaum et al. 2007b), as shrubs such as *Acacia mellifera* provide patches of shade, with concomitant patchiness in soil temperatures, moisture, and nutrient levels (Mazía et al. 2006). In highly overgrazed areas, however, shrubs become the dominant vegetation form, generating homogeneous patches (Skarpe 1990) with low habitat heterogeneity. In relative terms, nutrient levels also become uniformly high in response to nitrogen fixing by woody species and greater amounts of

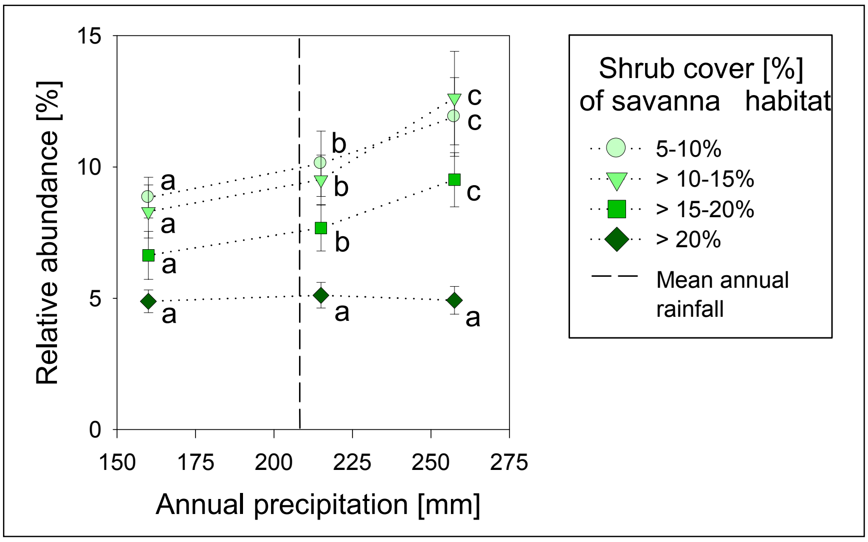

Fig. 14: The influence of annual rainfall on the abundance of small- and medium-sized mammalian carnivores in savanna habitats with different levels of shrub cover (category 1, shrub cover 5–10%, *N* = 6; category 2, shrub cover > 10–15%, *N* = 4; category 3, shrub cover > 15–20%, *N* = 6; category 4, shrub cover > 20%, *N* = 4). Annual rainfall was calculated between two subsequent rainy seasons i.e. from October of one year to September of the following year on the basis of the rainfall data of Twee Rivieren (South African Weather Bureau). Different letters indicate significant differences of carnivore abundance between annual precipitations of sample periods within a shrub cover category (repeated ANOVA; Tukey HSD Post Hoc Test, $p < 0.05$).

dung associated with higher livestock numbers. Despite the different responses, animal diversity across taxonomic groups was lowest for all taxa in areas where shrub cover was highest. Also the regeneration potential of animal populations in shrub-dominated areas during good rainfall years can be limited (Blaum et al. 2007b). For example, the abundance of small- and medium-sized carnivore populations increased with an increase in the amount of annual rainfall in savanna habitats where shrub cover is below 20%, whereas no increase was observed in habitats with shrub cover above 20% (Fig. 14).

As shown here, widespread shrub encroachment, caused by long-term, heavy grazing, threatens animal diversity in Thornbush Savannas. Nevertheless, moderate livestock grazing can even enrich Thornbush Savanna rangelands with positive effects for animal diversity since species richness across taxonomic animal groups was highest in Kalahari rangelands with medium shrub cover (12–18%). This needs to be considered when initiating shrub removal programs that aim at increasing grazing capacity. Understanding the relationships between species diversity and shrub encroachment is a crucial prerequisite to the development of management strategies that sustain both animal diversity and the landuser's profit.

Changes in bird diversity under shrub encroachment along a rainfall gradient

[R. Simmons & C. Seymour]

The effects of bush thickening are not always clear-cut as in the previous examples of mammals, reptiles and wingless arthropods. For birds, Seymour & Dean (2009) found that the presence of large trees within bush-encroached savanna landscapes obscures the effect of bush thickening on bird diversity and abundance. The effect of bush thickening on bird assemblages is, therefore, not simply related to the density of horizontal habitat, but also to the heterogeneity of the vertical habitat. Furthermore, Seymour & Simmons (2008) found that although species density (i.e. the number of species per area) was no different between encroached and non-encroached areas, species richness (species detected per number of birds surveyed) was greater in less encroached areas. Although flight enables birds to include larger shrub-dominated areas in their home ranges, shrub encroachment is nevertheless predicted to increase since under climate change because of the fertilisation effect that increased levels of CO_2 has on woody plants (Polley 1997) where rainfall may be limiting (Bond & Midgley 2000, Bond et al. 2003). Thus, drier areas may mimic what future climate change may bring to areas presently experiencing higher rainfall and bird communities in these areas may tell us how climate change will affect birds in each habitat type. In a recent BIOTA study in Namibia bird species-richness was compared between bush thickets and two alternative habitats (dry riverlines and open grassy areas), across a 260 km rainfall gradient with a drop in mean annual precipitation (MAP) of 257 mm/year. This represents a steep rainfall decline of roughly 1 mm/year for every km travelled mimicking possible climate-induced changes in years to come in Namibia. Within each site, three structurally different vegetation types were identified and sampled for birds. Habitats comprised: "Thicket" (dense shrubland comprising mainly *Acacia mellifera* and *Catophractes alexandri*), ephemeral dry "Riverlines" (with mature *Acacia* spp., *Ziziphus mucronata and Boscia albitrunca* trees) and "Open" areas dominated by grassland, with scattered *Acacia* spp. Bird species richness indices in the last dry season of monitoring (Aug. 2009) showed the same trends as in the first dry season (Aug. 2007), indicating across season consistency in resident bird assemblages. The aridity trends for bird richness in the thickets indicate that species richness (and diversity, H' $\log_e$) decline steadily from mesic to arid sites, (i.e. 30–7 species, Fig. 15).

Dry riverlines, however, showed no such decline from east to west (e.g. 28–28 species respectively), while open areas showed only marginal declines (i.e. 24–20 species respectively). This indicates that dry riverlines may play an increasingly important role in bird species diversity as global climate change creates more arid regions, as suggested by Seymour & Simmons (2008).

We next asked if bird assemblages in each area differed according to habitat and rainfall. Our results showed that for the four more mesic sites, bird assemblages were more similar between habitat types than between sites (e.g. riverine bird assemblages were similar, regardless of aridity), but a threshold was crossed at the most arid site. Bird communities at Rooiklip were more similar to each other regardless of habitat. In line with expected aridity effects on bird communities, the most **dissimilar** sites (at 83%) were those differing most in rainfall (Okasewa and Rooiklip). Combined, these results suggest that habitat is more important than aridity per se on bird community **composition** until very dry conditions are encountered. Across the aridity gradient habitat structure plays a role in species richness with the thickets losing species rapidly, while riverlines retain high species richness.

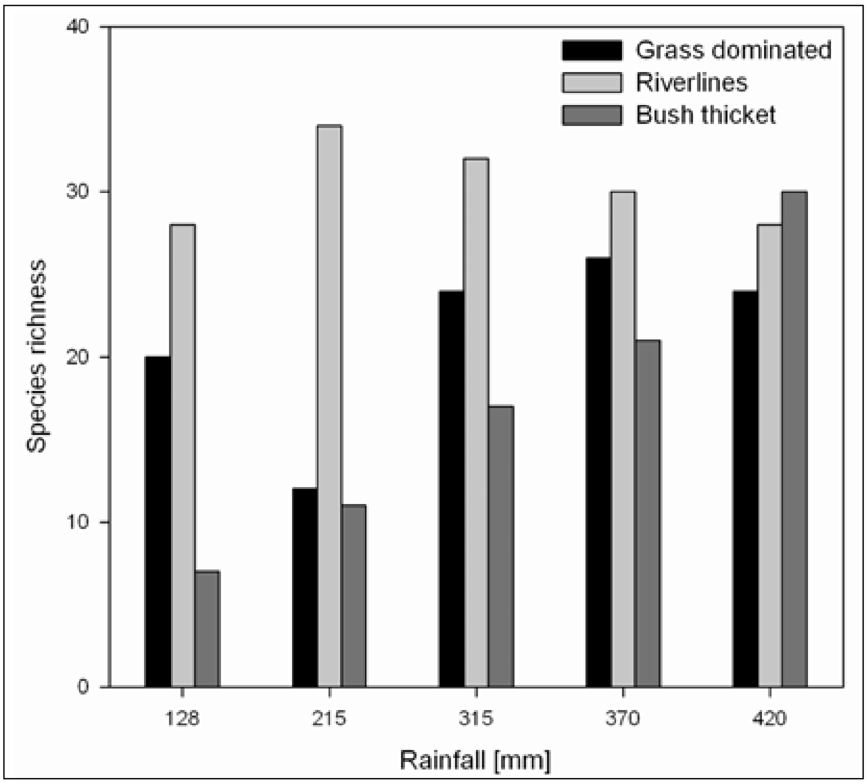

Fig. 15: Responses of bird species richness along an East-West rainfall gradient in Namibia for three major savanna habitat types. Black bars show grass-dominated savanna habitats, dark grey bars show bush thickets and light grey bars riverlines.

Understanding biodiversity dynamics—from single species to taxonomic groups

Background

[N. Blaum, E. Rossmanith & F. Jeltsch]
Understanding biodiversity dynamics under global changes in climate and landuse is a major challenge in modern ecology and a prerequisite for conservation planning. In Thornbush Savannas of southern Africa, many lessons on how animal diversity changes along landuse and climate gradients have been learnt from empirical studies within the BIOTA research framework (see under 'Identifying key patterns' in Subchapter IV.2.4; compare also Subchapters III.4.4 and III.4.5, Blaum 2008, Blaum et al. 2007a, b, c, 2008, 2009a, b, Popp et al. 2007, Meyer et al. 2009, Seymour & Simmons 2008, Seymour & Dean 2009, Thiele et al. 2008, Wasiolka et al. 2010). Based on such correlations between species diversity and environmental conditions, predictions on how species diversity may respond under changes in landuse and climate can be calculated. However, this static approach is often criticised because relevant processes such as dispersal, local adaptation, interactions, and transient dynamics are often not included (e.g. Thuiller et al. 2004). Process-based, dynamic simulation models are an alternative and promising approach (Guisan & Thuiller 2005) and have been applied in several BIOTA studies (e.g. Wichmann et al. 2003, Blaum & Wichmann 2007, Popp et al. 2007, Schwager et al. 2008). In these models, all important processes of a population dynamics are simulated. Based on the known effects of the environment (e.g. climatic conditions) on specific processes of population growth, physiology, or behaviour, dynamic population models project the details of population dynamics into the future under scenarios of environmental change (e.g. induced by climate or landuse). In comparison to static approaches, dynamic population models have the inherent advantage of not accepting a species' response to a certain climate as static but as result of certain mechanisms and processes. Still, most process-based dynamic simulation models require many data for parameterisation and are thus often based on single species approaches (e.g. Wichmann et al. 2003, Tews et al. 2006, Blaum & Wichmann 2007, Popp et al. 2007, Schwager et al. 2008). Although these approaches allow for the development of specific management recommendations for decision support of a single species, recommendations for a wider range of species with, for example, different home range requirements and dispersal abilities are limited. To predict changes in biodiversity dynamics based on a single species approach is impossible under reasonable time and cost frames. Therefore, a generic modelling approach was developed, where the impacts of landuse and climate changes can be simulated for a set of species.

In the following section, the results of two modelling approaches will be presented, where the impact of landuse on species diversity and abundance was analysed for multiple species.

Sensitivities of mammalian carnivores to landuse at scales relevant for decision makers

[N. Blaum, E. Rossmanith & F. Jeltsch]
Analysing the effects of land management on biodiversity dynamics requires the explicit consideration of scale-crossing mechanisms and process-interactions. For example, the germination and establishment of plants act at very small and local

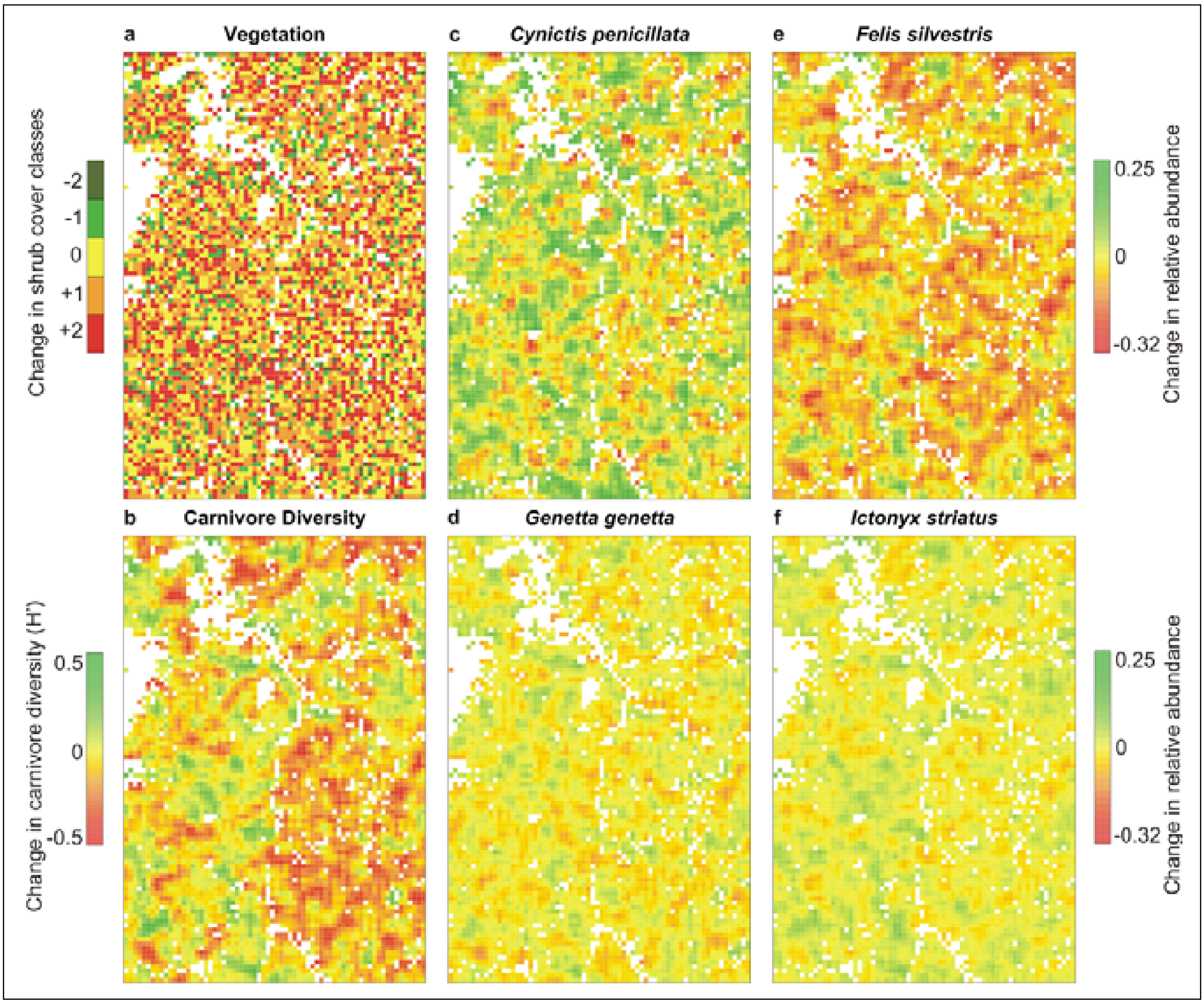

Fig. 16: Simulation results of the upscaled vegetation and carnivore model. Tested scenario: 20% increase in grazing intensity on all farms. Shown are differences between current status quo and changes after 20 years. Panel a (top left): The upscaled model assumes three shrub cover classes: low shrub cover < 10%, medium shrub cover 10–20% and high shrub cover > 20%. Panel a shows the changes in shrub cover classes (–1 indicates a decrease of shrub cover of one class, i.e. from high to medium shrub cover or from medium to low shrub cover). Panel b (bottom left): Changes in carnivore diversity (Shannon Index). Panels c–f: Changes in relative abundance of c: Yellow Mongoose (*Cynictis penicillata*), d: Small Spotted Genet (*Genetta genetta*), e: African Wildcat (*Felis sylvestris lybica*), and f: Striped Polecat (*Ictonyx striatus*).

scales while the dispersal of animals and the decisions made by land managers can act at large and often regional scales. The integration of such contrasting scales was successfully done combining the analysis of a small scale vegetation model and a state-and-transition approach (Jeltsch et al., in press). This upscaled vegetation model was combined with a multiple species approach to analyse the impacts of land management on mammalian carnivores in a southern African Kalahari rangeland system. The simulated Kalahari rangeland system (75 km x 100 km) is characterised by a mosaic of livestock farms, with different stocking rates and farm sizes (3,000 ha to 20,000 ha). In a first step, a grid-based landscape model (grid-cell size 1 km²) was developed, which includes specific grazing intensities for all farms. The savanna vegetation was simulated dynamically using a state-and-transition approach (Westoby et al. 1989). Transition probabilities of typical Thornbush Savanna vegetation states (defined by a specific proportion of shrub and perennial grass cover) under different grazing intensities and annual rainfall were derived from simulation experiments with a small-scale process-based vegetation model (5 m by 5 m grid-cell size, Jeltsch et al. 1997a) on 1 km². In particular, the frequency of occurrence of transitions between two vegetation states served as transition probabilities that were used to simulate the change in vegetation for each of the 7,500 one square kilometre patches of the landscape model (i.e. the whole rangeland area; see Fig. 16 for an example).

In a second step, the large scale vegetation model was linked to statistical models of carnivore abundance and species richness field data (Blaum 2008, Blaum et al. 2007a, b, 2008, 2009a) including an algorithm describing neighbourhood effects. The current vegetation for the study area was derived from remote sensing data, which were ground truthed by several hundred vegetation surveys in the field. Current grazing impact was derived from own farm surveys and stocking data from the extension office in Upington. In the sample scenario shown in Fig. 16, stocking rates were increased by 20% for a period of 20 years. The results of this combined large-scale savanna landscape and carnivore diversity model shows a large scale degradation of the savanna vegetation with differing sensitivities of carnivores within one guild (Fig. 16). While Yellow Mongooses (*Cynictis penicillata*) showed positive as well as negative responses to the predicted changes, the abundance of Wild Cats (*Felis sylvestris lybica*) declined in most habitats. Similarly, the abundance of Small-spotted Genets (*Genetta genetta*) decreased slightly while minor effects were predicted for Striped Polecats (*Ictonyx striatus*). The ambivalent responses of Yellow Mongooses to predicted habitat changes can be explained by their dependency on single shrubs for sheltering and reproduction (for details see Article III.4.6). This large-scale vegetation model can also be used for other applications such as landuse optimisation models (for an example see Article III.7.4), linkage to dynamics population models of animals with large home ranges or dispersal models (Chapter III.2).

Effects of landuse on bird populations—a generic functional type modelling approach

[E. Rossmanith & N. Blaum]

As stated above (see ‘Uderstanding biodiversity dynamics’ in Subchapter IV.2.4), to better understand the dynamics of biodiversity we need to transfer knowledge gained from single species to a more generalised multiple species approach. This has led to the development of categorisation systems, where species’ similarities in life strategies and traits within and between communities are classified into functional groups or types (e.g. Lavorel & Garnier 2002, Blondel 2003). Functional types were initially defined as “a non-phylogenetic classification leading to a grouping of organisms that respond in a similar way to a syndrome of environmental factors” (Gitay & Noble 1997). The classification is based on a set of functional traits that are considered important for a species’ response to the environment. While much emphasis has been set on the identification of key traits and functional types in plant ecology (e.g. Lavorel & Garnier 2002, Cornelissen et al. 2003, Poschlod et al. 2003) examples where animal species were identified as functional groups are scarce. For savannas, functional approaches for animals are mainly restricted to grazing ungulates and their effects on vegetation (e.g. McNaughton 1993, du Toit & Cuming 1999).

One reason that functional classification schemes have hardly been developed further in animal ecology might be the difficulty in defining clear core traits due to the high variability in behaviour, foraging strategies, resource needs and morphology of animals compared to plants. For savanna systems, the combined effects of landuse and climate on key habitat structures and on resource availability demand the identification of (i) core animal traits describing species‘ dependency on their habitat as well as (ii) life history traits that are related to the processes of birth, survival, and movement. Orienting process-based, bottom-up models towards the response of functional types instead of single species and identifying traits that react most sensitively will allow for the derivation of more general results with regard to understanding and predicting the effects of environmental change on savanna biodiversity.

As indicated earlier, one major environmental change in the savannas of southern Africa is shrub encroachment and the loss of perennial grass cover due to overgrazing. This change in habitat can reduce the availability of food resources, such as grass seeds, insects, and vertebrate prey species, for birds (e.g. Blaum et al. 2007b, c, 2009a). Habitat change also decreases the availability of grass needed for nest construction. On the other hand, shrub encroachment will increase shrub-associated, prey species as well as nest sites for shrub-nesting bird species. Besides grazing, wood cutting for fire wood production is an important landuse option, which decreases tree density and changes spatial patterns of trees (Anderson & Anderson 2001). For many bird species, trees are important structures for nesting or as a raised stand for hunting. Thus, depending on the traits and trait combinations of birds, predicted landuse induced changes will have different effects.

To investigate the effect of shrub encroachment and tree removal on bird species in Thornbush Savannas, a generic functional type model was developed for birds, which simulated the population dynamics of a large variety of functional types, characterised by the combination of functional traits. Parameterisation of life history traits (reproductive rate, survival rate, age of maturity, home range size and dispersal distance) were derived from the allometric relationships with body mass. Since reproductive rate is strongly influenced by latitude (Lack 1947, Skutch 1985), this trait was derived from a meta-analysis of 135 bird species in the study area (southern Kalahari, including Observatory Alpha, S17). All other allometric relationships were derived from meta-analyses in the literature (Calder 1984, Saether 1987, Prinzinger 1993, Bowman 2003, Ottaviani et al. 2006). Traits that are particularly important for birds in Thornbush Savannas under changing habitat due to landuse were food preference [(i) herbivorous/carnivorous, (ii) insectivorous/omnivorous, and (iii) carnivorous], and nest site needs (trees, shrubs, ground). Together with body mass, these three traits were systematically varied and combined to test their effect on a large variety of bird functional types.

The model is spatially-explicit and is based on a landscape grid, which is characterised by the proportion of shrub and grass cover as well as the number of trees and the spatial patterns of these vegetation structures (see Fig. 19 as an example of different tree clumping scenarios). A home range grid is projected on top of the landscape grid, with 15 x 15 cells of the size of a home range where the cell size for a particular bird functional type is determined by the respective body mass. For each home range cell, vegetation composition was calculated, and this in turn influenced (together with simulated stochastic rainfall) the habitat quality. Changes in the population dynamics proceeded in annual time steps and the habitat quality of the home range then influenced

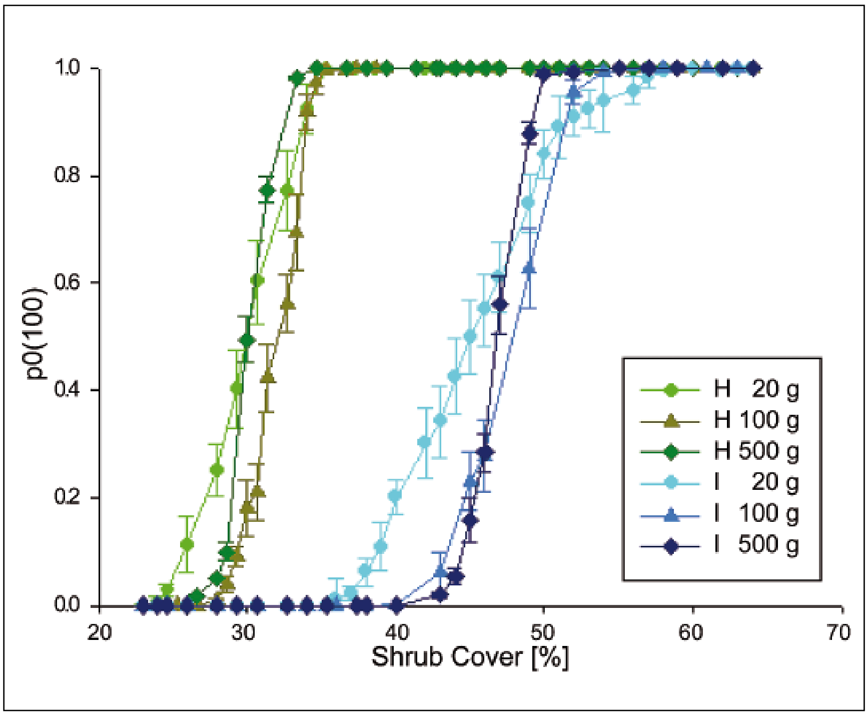

Fig. 17: Effects of shrub encroachment on extinction probability within the next 100 years ($p_0(100)$) for herbivores/granivores (H) and insectivorous/omnivorous (I) birds of three size classes. The class of small-sized birds (0–50 g) was represented by simulating a 20 g bird, the class of medium sized birds (51–300 g) by a 100 g bird and the class of large sized birds (> 300 g) by a 500 g bird. The mean and standard error of 30 runs are shown. Each run simulates 100 populations with identical landscape and parameterisation.

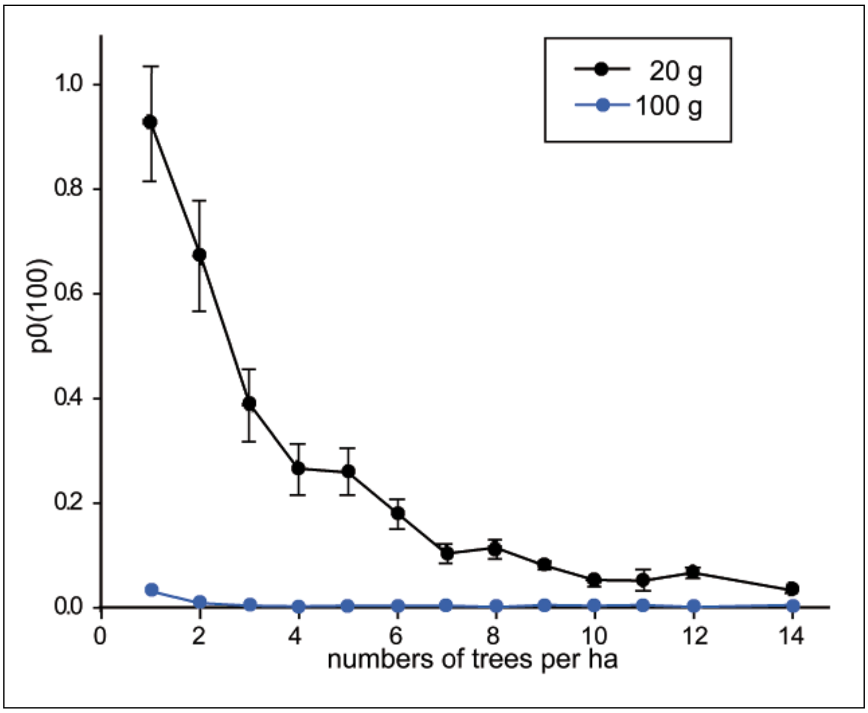

Fig. 18: Effect of tree density on extinction probability within the next 100 years of tree nesting birds in three size classes. The mean and standard error of 30 runs are shown. Each run simulates 100 populations with identical landscape and parameterisation. Spatial pattern was scenario "low clumping", which is comparable to the existing pattern of trees in the study area.

the reproductive success and the survival rate of its inhabitant. Using this model, the effect of different shrub encroachment as well as tree removal scenarios on the persistence of functional bird types could be tested.

The results of the simulation model show that shrub encroachment will increase the risk of extinction for all tested functional types. However, herbivorous birds respond more sensitively to shrub encroachment then insectivorous birds (Fig. 17). This is supported by Sirami et al. (2009), who found for bird assemblages that carnivorous and other birds associated with grasses decreased as the percentage of shrubs increased whereas insectivorous species increased. Even though there are slight differences in extinction risk between birds of different size classes, the results show that the trait reacting most sensitively to shrub encroachment is food preference.

For tree nesting species, the model predicts a strong increase in extinction risk with decrease of tree density for small birds but almost no effect on medium-sized and large birds when trees are distributed randomly (Fig. 18). The reason for this pattern is that the smaller home range sizes evident within small birds (Ottaviani et al. 2006), will result in a lower likelihood of finding a tree at given densities then for birds with large home ranges. However, the spatial pattern has a large influence on the persistence of populations, since stronger clumping of trees will also affect negatively the extinction risk of medium-sized and large tree-nesting birds (see Fig. 19 for medium-sized bird). Model results show that not only the remaining tree density but also their spatial pattern should be considered when removing trees for firewood and charcoal production.

2.5 Risk assessments

Savanna vegetation

[M. Wieczorek, N. Blaum, H. Rubilar, E. Rossmanith, D. Lohmann & F. Jeltsch]

Namibian savannas are threatened by climate change and unsustainable land-use. Both, taken separately or in combination, can lead to degradation. This can occur either as a general loss of vegetation cover and an increase of bare patches or an increase in woody and less palatable vegetation (see 'Remote sensing' in Subchapter IV.2.2). While the loss of palatable, perennial herbaceous vegetation is a general risk accompanying all types of savanna degradation the specific outcome of climate change and overgrazing depends not only on the rainfall amount and regime but also on the soil type and the actual vegetation type and cover (see Subchapter IV.4.3 and Article III.2.4).

To assess the risk of degradation in Namibian savannas, we applied the ecohydrological model EcoHyD (Tietjen et al. 2009a, b; see also Subchapter IV.2.3) to six different savanna sites that represent rainfall regimes with MAP (mean annual precipitation) between 200 mm and 500 mm and to four different soil types (loamy sand, sand, sandy clay loam, and sandy loam). These 'site – rainfall regime – soil' combinations represent a broad range of environmental conditions specific to a large part of Namibian savannas (Fig. 21). In addition to the variable combination outlined above, grazing was also varied in these areas according to four different categories, from low to very high grazing intensity, quantified as 2%, 5%, 10%, and 20% grass cover removal per year by livestock grazing that needed to be compensated for by regrowth. To allow for better comparison, the same topography was applied to all areas in the model. For all rainfall-soil combinations within this focal savanna region we systematically tested the risk of vegetation degradation under the different levels of livestock production for scenarios with and without climatic change. For climate change scenarios the MAP of each region was assumed to decrease by 10% and the mean annual temperature was assumed to rise by 2.25°C (compare Subchapter IV.2.3 and Article III.7.2).

To calculate the risk of degradation for every site, we assessed the relative decrease of perennial grass cover as the most important aspect of degradation risk. We also looked at the risk of shrub encroachment, which we defined as a relative increase of shrub cover of more than 5% in the given time frame and an absolute value of shrub cover higher than 5% (striped areas in Figs. 21 & 22).

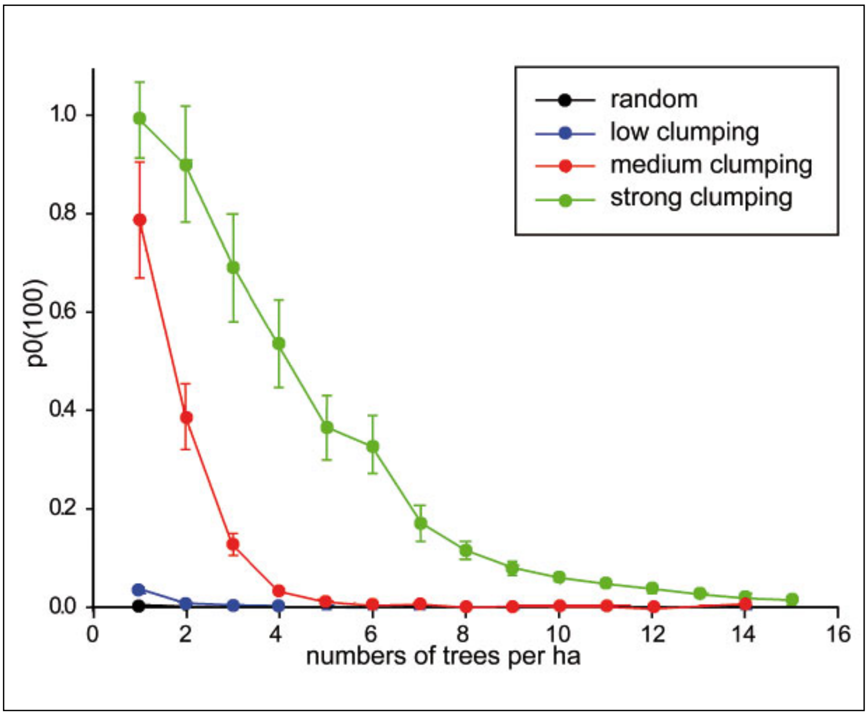

Fig. 19: Effect of tree density on extinction probability of medium-sized birds under four different scenarios of spatial patterns of trees. The mean and standard error of 30 runs are shown. Each run simulates 100 populations with identical landscape and parameterisation.

The risk assessment maps (Figs. 21 & 22) clearly show the increasing degradation risk with higher grazing intensities, which is further enhanced by expected climate change. Different soil conditions also have a strong influence on the risk of vegetation degradation and on the impact of climate change. Soil type also influences the risk of shrub encroachment, which is further modified by climate change. In general, the tested climate change scenarios, which did not include increased CO_2 levels (compare Subchapter IV.2.3 and Article III.7.2), reduced the tendency towards shrub encroachment but also led to an decrease in overall vegetation cover and thus an increased risk of erosion (see Figs. 21 & 22).

Risk assessment of a medicinal plant—the Devil's Claw

[S. Schütze, N. Blaum, H. Rubilar, E. Rossmanith, D. Lohmann & F. Jeltsch]

To assess the risk of population decline of the Devil's Claw (*Harpagophytum procumbens*) under landuse and climate change in Namibian savannas, we used the above-predicted changes in vegetation cover (Figs. 21 & 22) as landscape input for the Devil's Claw model described in Article III.7.6 (Schütze 2009). For each of three landuse scenarios (low grazing, moderate grazing and high grazing impact), and one climate change scenario (details described above in 'Savanna vegetation', Subchapter IV.2.5), the impacts of two different harvesting strategies on the change in Devil's Claw population size after 100 years were simulated. Harvesting scenario 1 was a sustainable harvesting strategy with a moderate removal rate of secondary tubers and a three year harvesting cycle that was identified by the model of Schütze (2009) and supported by expert knowledge (Strohbach, pers. comm.). Harvesting scenario 2 reflects a common strategy where high amounts of secondary tubers are harvested annually (Strohbach & Cole 2007, see also Article III.7.6).

Model results show that the impacts of the harvesting strategy on the relative change in size of Devil's Claw populations is much stronger than the predicted impacts of the livestock management and climate change scenarios (Figs. 23 & 24). However, predicted climate change increases the negative effects of unsustainable harvesting on Devil's

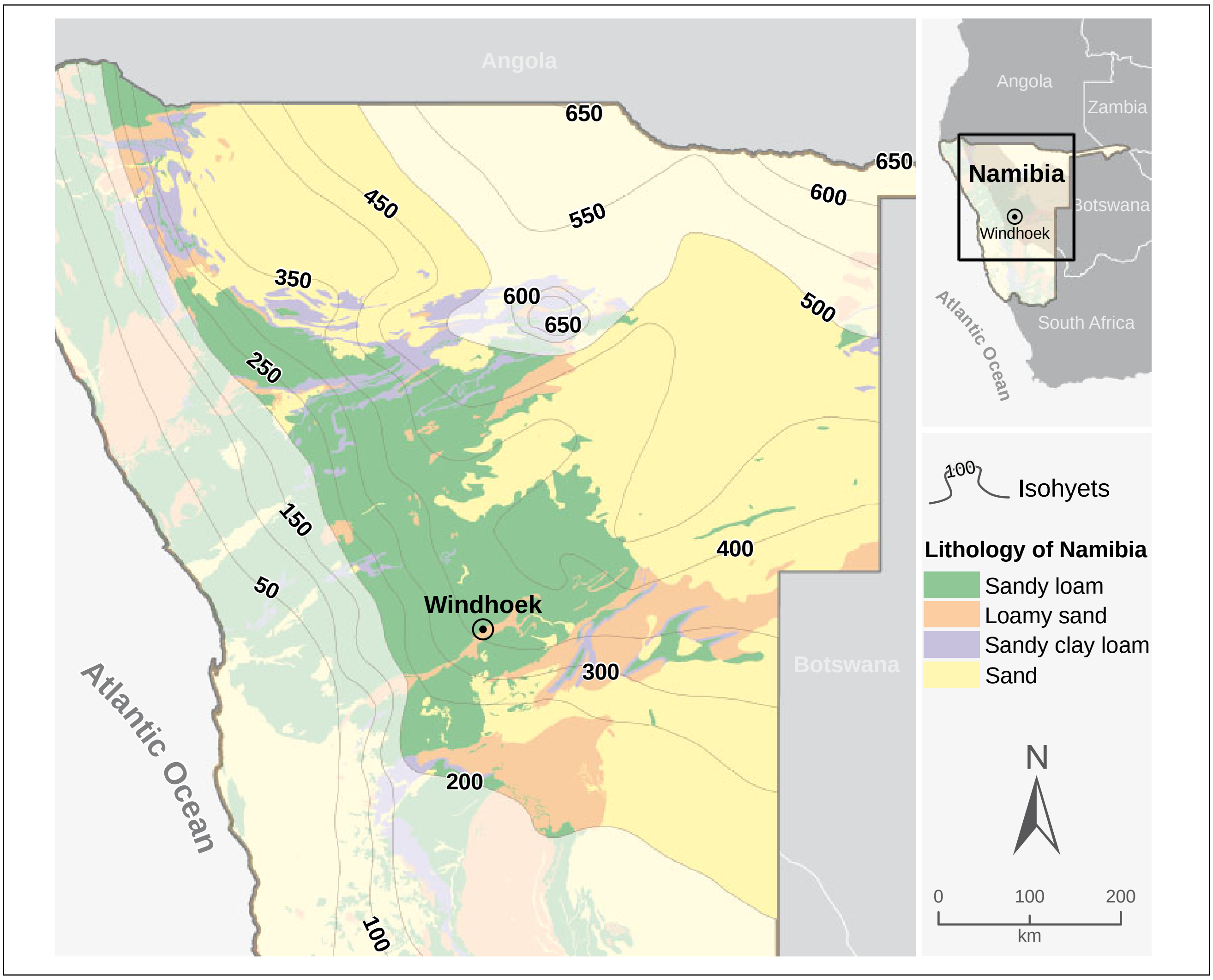

Fig. 20: Lithology of Namibia with rainfall isohyets for the risk assessment maps in the focal Namibian savanna region. Figure modified from Christelis & Stuckmeier (2001), with permission from the Ministry of Agriculture, Water and Rural Development, Department of Water Affairs, Division Geohydrology, Namibia.

Claw population size across the study region (Fig. 24). The model predicts that the most sensitive region in Namibian Thornbush Savannas is the most southern region with the lowest amount of rainfall.

Risk assessment of bird functional types

[E. Rossmanith, N. Blaum, H. Rubilar, D. Lohmann & F. Jeltsch]

To assess the extinction risk of birds under landuse and climate change in Namibian savannas, we used the above predicted changes in vegetation cover after 30 years (Fig. 22) as landscape input for the animal functional type model described under ‘Understanding biodiversity dynamics’ in Subchapter IV.2.4. The Figures shows the extinction risk of insectivorous (Fig. 25) and herbivorous (Fig. 26) birds. Since there were only slight differences in the results for different size classes, only results for small birds (body mass < 50 g, which comprise 54% of the species in the area) are shown. The extinction risk is given as the probability of extinction within 100 years ($p_0[100]$).

The model predicts no threat for small insectivorous birds as a result of habitat change, except for a slight increase in extinction risk under very high grazing impact (Fig. 25). For herbivorous birds, however, the model predicts increased extinction probabilities of up to 50% under high and very high grazing impacts (Fig. 26). Especially in areas with low rainfall, the extinction risk increases even under moderate grazing impacts when the climate change scenario is added to the model. This spatial pattern is determined by the relative loss of perennial grass, which is the primary food resource (compare Fig. 22). The results emphasise the high sensitivity that herbivorous birds have to changes in habitat caused by overgrazing or climate change. However, we need to be cautious in applying these results to specific bird species, since species-specific life-history traits, potential buffer mechanisms and behavioural adaptations to environmental changes were not considered in this analysis and might have an important influence on extinction risk.

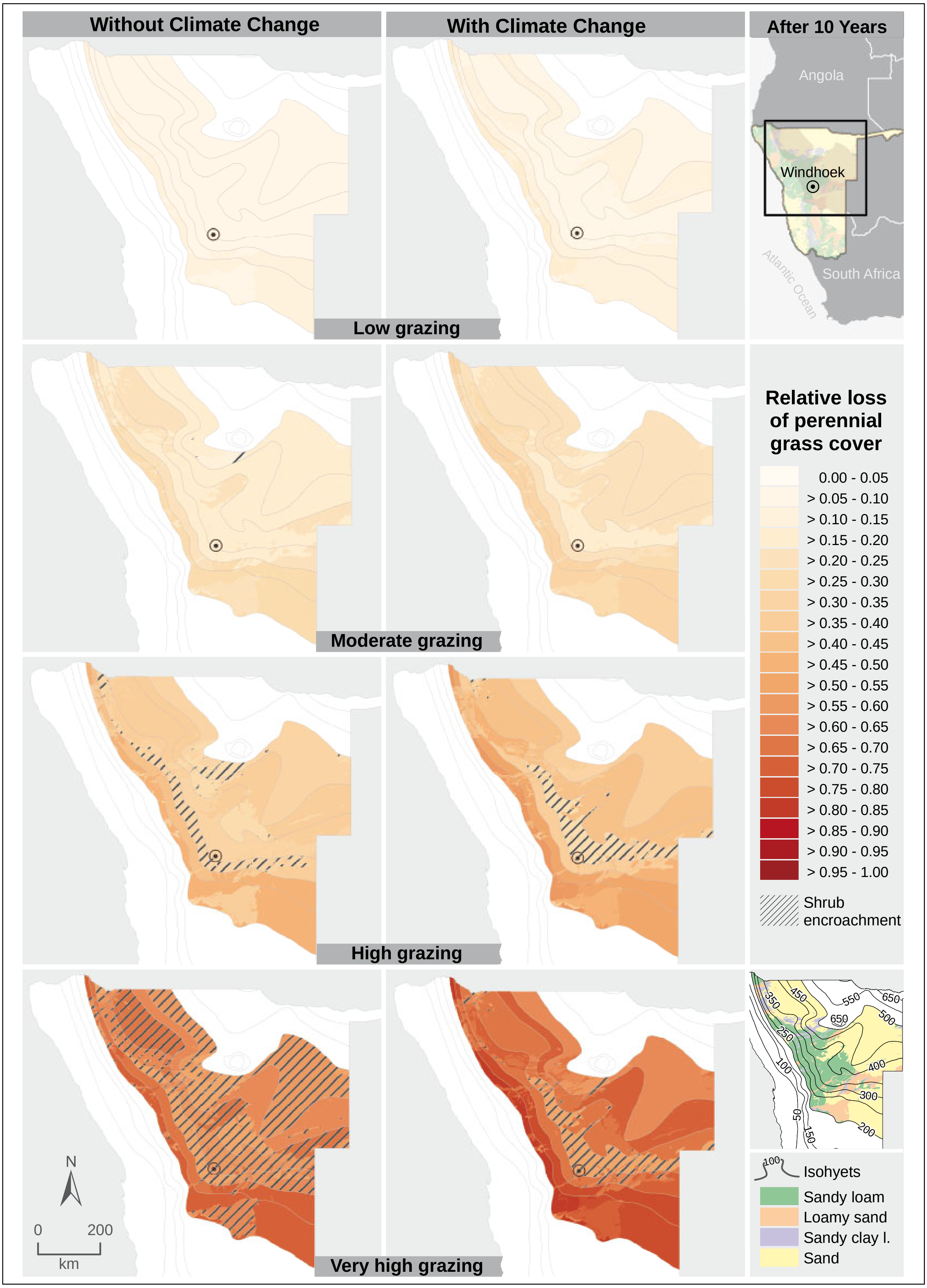

Fig. 21: Risk assessment maps of predicted vegetation changes for the focal Namibian savanna region over 10 years under low to very high grazing intensities without and with climate change. Colour shades indicate different levels of relative loss of perennial grass cover. Striped areas indicate a principle, additional risk of shrub encroachment (for details, see text).

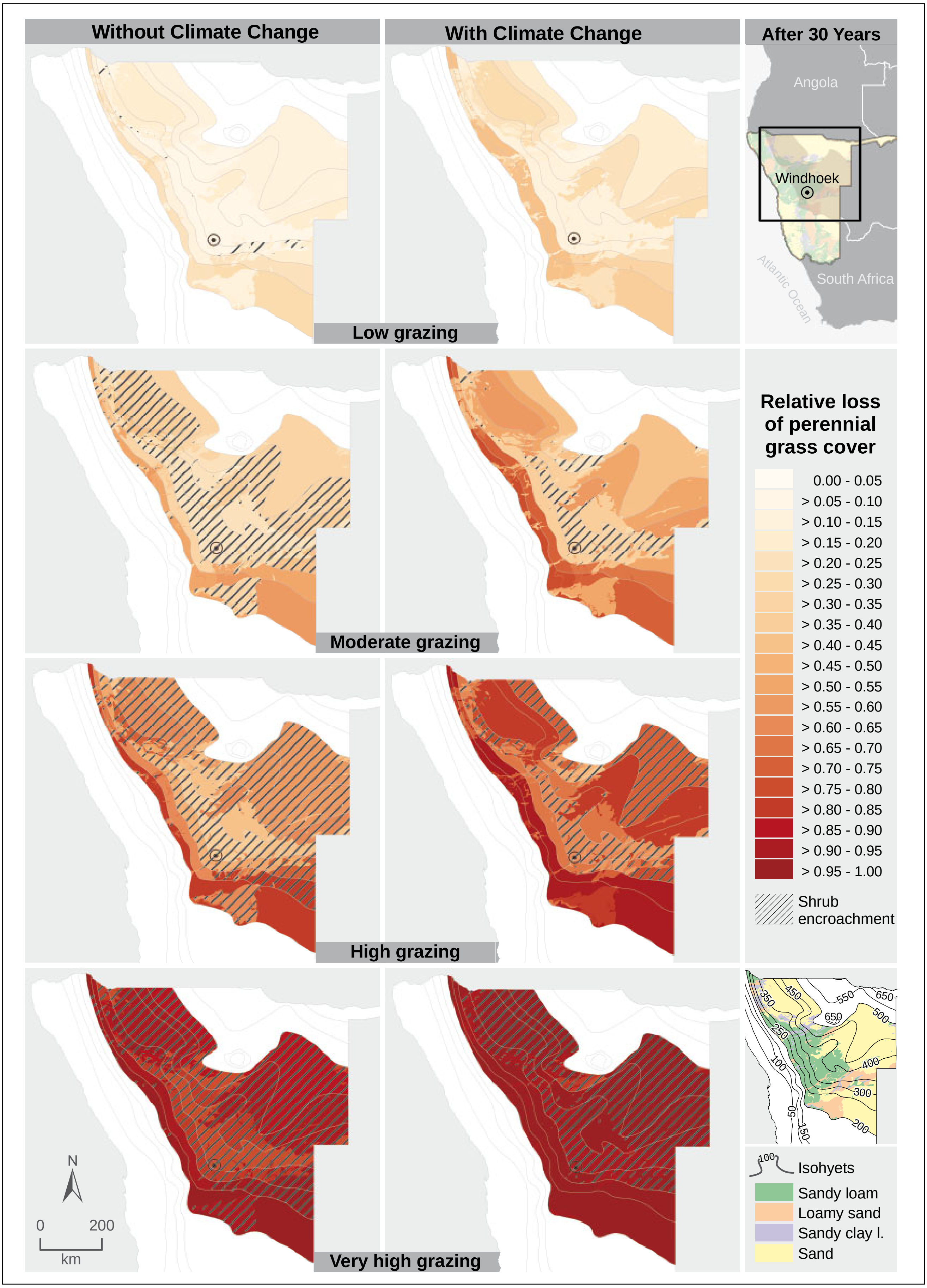

Fig. 22: Risk assessment maps of predicted vegetation changes for the focal Namibian savanna region over 30 years under low to very high grazing intensities without and with climate change. Colour shades indicate different levels of relative loss of perennial grass cover. Striped areas indicate a principle, additional risk of shrub encroachment (for details, see text).

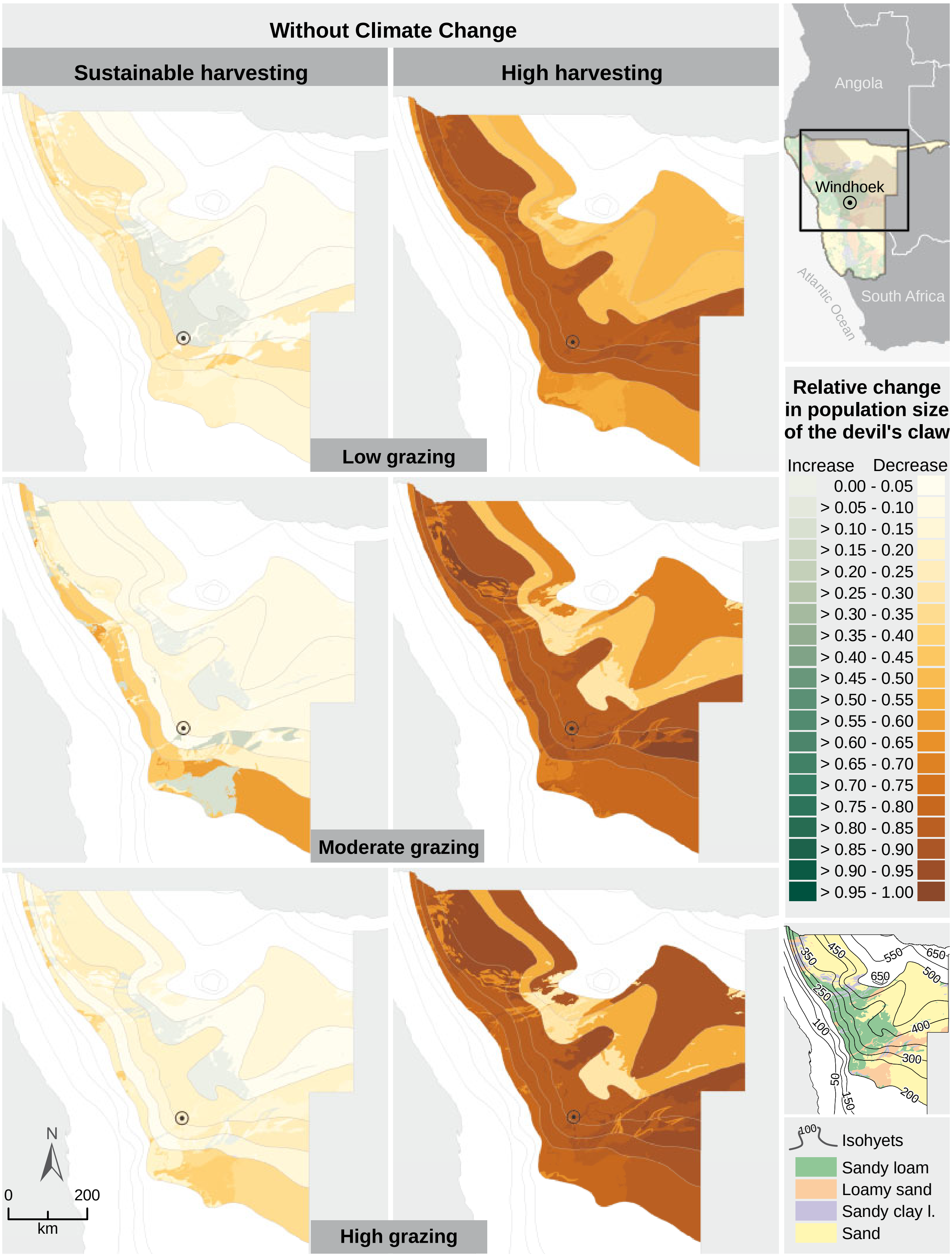

Fig. 23: Risk assessment maps for Devil's Claw (*Harpagophytum procumbens*) in the focal Namibian savanna region under three grazing scenarios and two harvesting strategies without climate change. Colour shades indicate the relative change in population size of Devil's Claw after 100 simulation years.

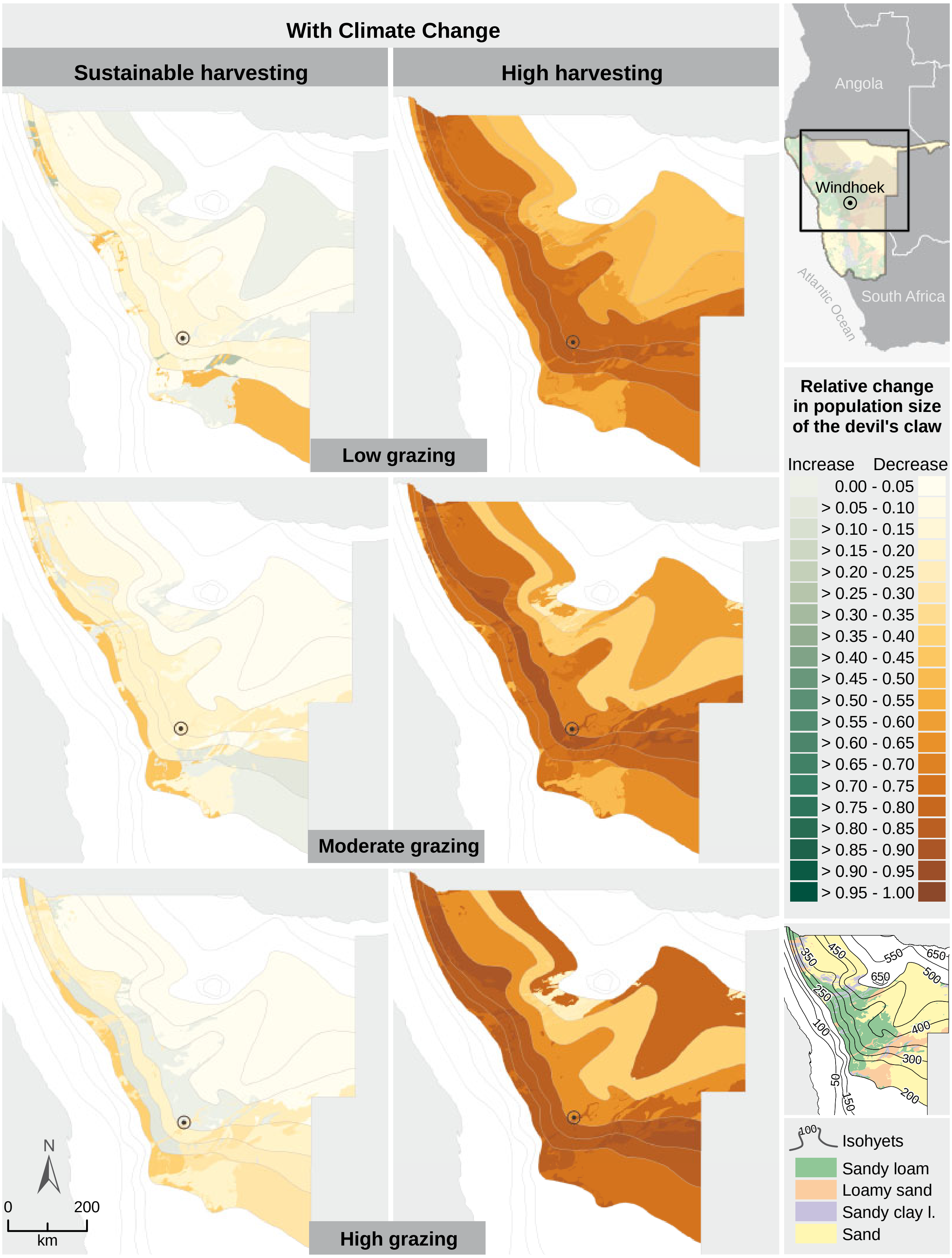

Fig. 24: Risk assessment maps for Devil's Claw (*Harpagophytum procumbens*) in the focal Namibian savanna region under three grazing scenarios and two harvesting strategies with climate change. Colour shades indicate the relative change in population size of Devil's Claw after 100 simulation years.

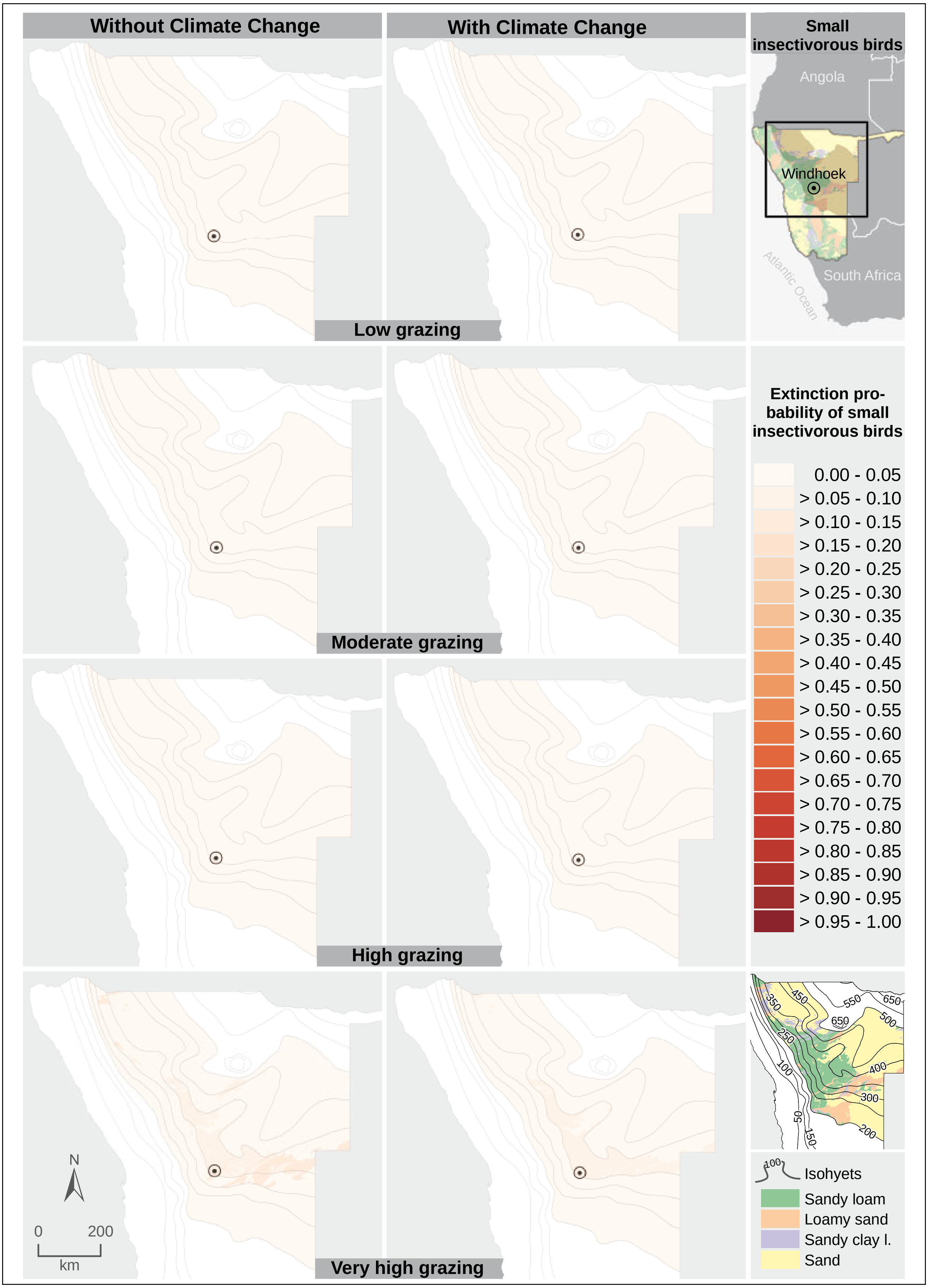

Fig. 25: Risk assessment maps for small (< 50 g) insectivorous birds in the focal Namibian savanna region based on predicted vegetation changes after 30 years for different grazing intensities with and without climate change. Colour shades indicate the extinction probability within the next 100 years, $p_0(100)$.

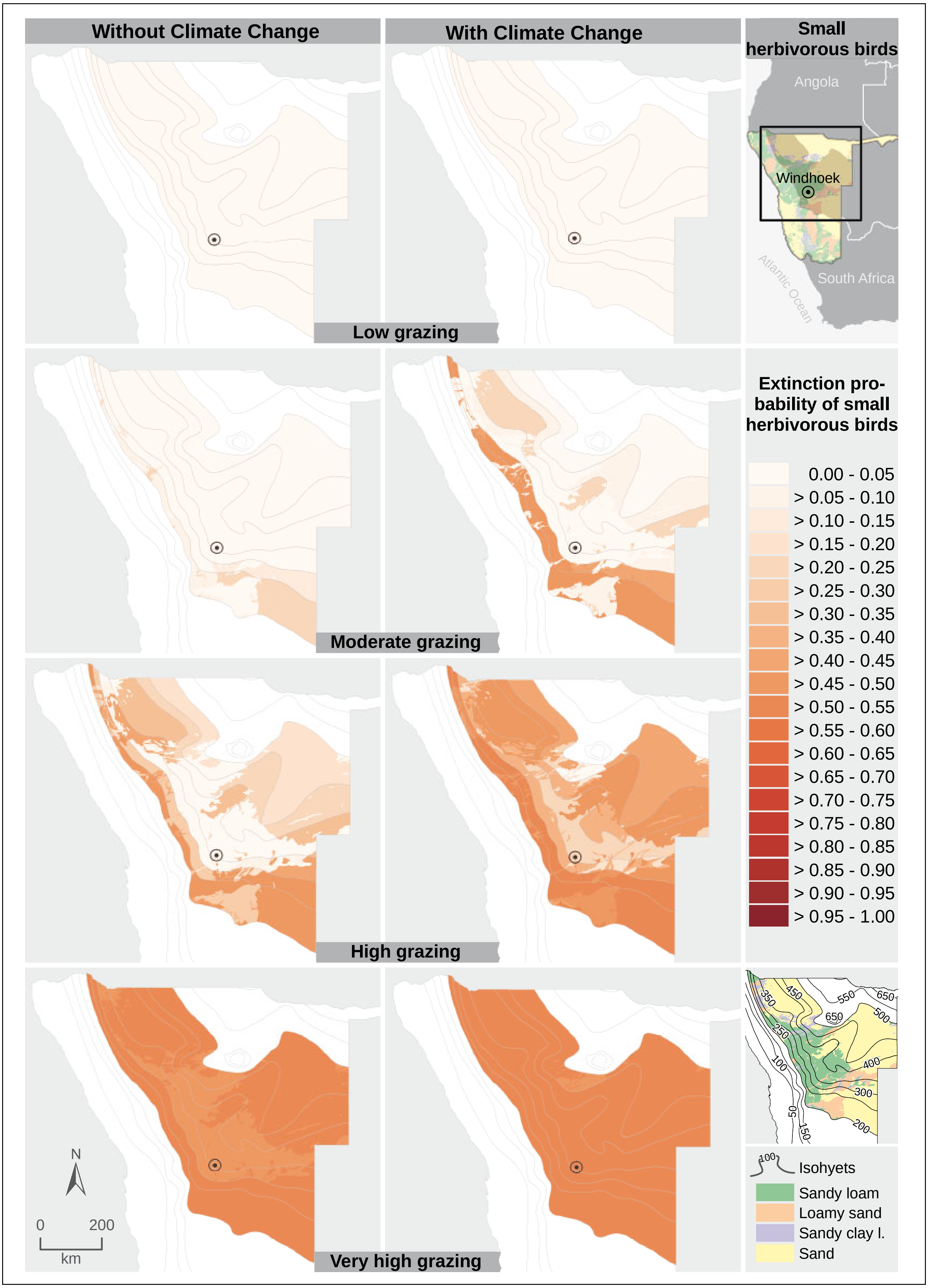

Fig. 26: Risk assessment maps for small (< 50 g) herbivorous birds in the focal Namibian savanna region based on predicted vegetation changes after 30 years for different grazing intensities with and without climate change. Colour shades indicate the extinction probability within the next 100 years, $p_0(100)$.

2.6 Integrated socio-economic and ecological research

[D. Lohmann, T. Falk, E.-A. Nuppenau, E. Rossmanith, N. Blaum & F. Jeltsch]

Background

The semi-arid Thornbush Savannas of southern Africa are not only unique, diverse and fascinating ecosystems, they also contribute to the regional and national economy since they are widely used, for example, for livestock production and tourism. At the same time, these ecosystems are sensitive to over-utilisation resulting in ecological degradation and decreased capacity to deliver ecosystem services. The degradation of the vegetation (i.e. the loss of perennial grasses often accompanied by an increase of woody vegetation) causes a loss of palatable plant biomass with good nutritional value for livestock. It can further result in lower soil moisture levels caused, for example, by a decrease in water retention due to lower infiltration rates.

There are many reasons why some natural resource utilisation systems result in the degradation of savannas. For example, the limited availability of information on complex biotic and abiotic processes and feedbacks and short- or long-term consequences of specific management actions can promote degradation processes. The semi-arid Thornbush Savannas of southern Africa are highly complex eco-hydrological systems that are driven by highly erratic rainfall conditions (see e.g. Article III.7.2). Understanding observed dynamics and assessing possible future responses is a challenge for resource managers especially since human impacts are often only visible on large temporal scales. One objective of integrated research is therefore to present the key aspects of complex systems in a simplified way (e.g. by modelling or developing generalising theories) in order to make it easier for decision-makers to deliberate about the consequences of their decisions. But even if causal links of natural processes are clear, human decisions depend on the dynamics of complex social systems, which need to be understood as well. A typical challenge for sustainable natural resource management is the occurrence of externalities. If a person does not have to cover the full costs or does not receive the full benefits of resource use then she/he might be more inclined to overexploit the resource. Cultural, customary, and statutory institutions have the objective to internalise externalities but often fail due to high transaction costs.

Therefore, developing well-adapted resource use strategies requires a good understanding of both the ecological as well as the socio-economic systems. This includes the assessment of the feasibility and acceptance of such strategies amongst relevant stakeholders. Fulfilling this task is only possible by strong interdisciplinary cooperation as has been practiced within the BIOTA project.

In the special case of the Thornbush Savanna that is addressed in this chapter, the main focus of ecological-economic research lies in the identification of sustainable use practices of the savanna ecosystem for livestock production. Socio-economic studies using the Institutional Analysis and Development (IAD) framework (Ostrom et al. 1994) as well as the Capital-Need-Institution framework (Falk 2008) assessed the farmers' capital availability, their landuse objectives, and the institutional set up as key determinants of resource use decisions. Empirical data were collected using in-depth case studies as well as semi-structured interviews. In addition, group discussions and participatory observations were utilised in order to learn about common practices and perceived challenges (see e.g. Article III.5.3 and III.7.5). Ecological studies are also available, which describe the drivers and dynamics of the shrub encroachment problems and vegetation dynamics in general (e.g. Article III.7.2 and Subchapter IV.2.5).

Integrated projects including both ecological and economic research have been conducted in the Thornbush Savannas of Namibia during the BIOTA project. Two relevant studies are introduced briefly below in order to depict the structure and potential of the conducted integrated projects. More detailed information about the results of these studies can be found elsewhere in this book (Articles III.7.5 and III.5.3) or in Buß (2006).

Integrated study 1: bio-economic modelling in central Namibia—using optimisation to identify suitable landuse strategies

This chapter introduces a study on optimal farm management in the Okahandja District of central Namibia that is based on an empirical study and the dynamic, non-linear programming of a bio-economic model (Article III.7.5, Buß 2006). The study in general deals with several questions related to sustainable rangeland management, one of which will be described here in order depict its methodology, structure and potential. The example that we present here contributes to an understanding of the potential influence of climate change on an optimal rangeland management strategy.

The empirical part of the study (consisting mainly of interviews) was conducted on regional "best-practice farms". These data, in combination with data from research stations in the area and information from local experts have been used to identify possible landuse options and their costs. In order to simulate the impact of management options on natural resource dynamics a state-and-transition conceptual model (Westoby 1989, Popp et al. 2009c, Joubert et al. 2008a, Article III.7.2) was applied. In cooperation with rangeland ecology experts (Rothauge 2002) different stable vegetation states and probabilities for transitions between these states have been defined. The various sets of management options and corresponding ecological impacts that were developed from this approach then served as the input for a dynamic bio-economic model using the General Algebraic Modelling System (McCarl 2002) in order to identify optimal management strategies. Simulations of a 10,000 ha farm for 30 years were conducted, which accounted for the average farm size of surveyed farms and a time horizon that is relevant from a landusers' but also from an ecological perspective. Stochastic rainfall time-series were also applied, since unpredictable rainfall is one of the key problems for landusers in semi-arid savannas.

In general, the results of such a data-based simulation-optimisation approach provide optimal landuse strategies for

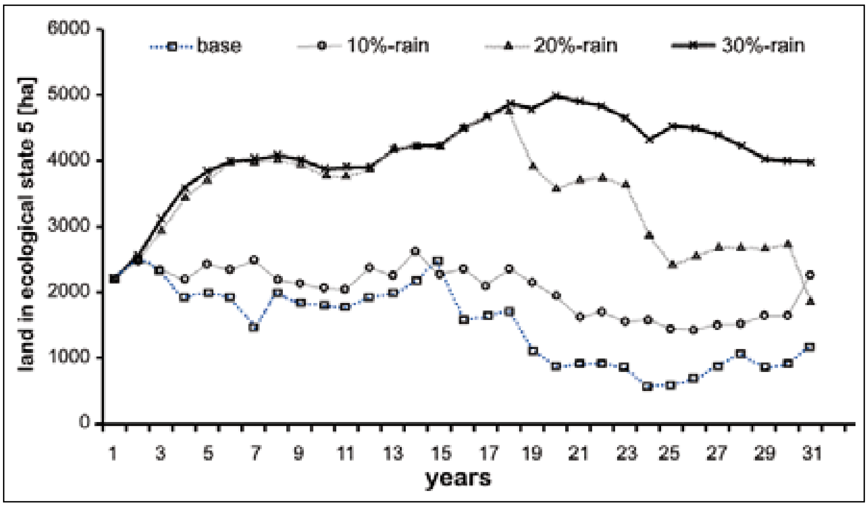

Fig. 27. Area of a farm under optimal management that is degraded (shrub encroached, state 5) for a baseline scenario and three scenarios with 10, 20, and 30% reduction of annual precipitation. Source: Buß (2006).

given objectives. Such objectives include, for example, the development of maximum profit, maximum ecological sustainability, or hybrids of these objectives. In more detail this means that the model determines the best option from the above described set of options for every decision in each of the 30 years.

The programmed model is capable of simulating different scenarios. As mentioned above we wanted to show only one snapshot result as an example here. Fig. 27 shows differences among optimal rangeland management strategies for four climate change scenarios regarding the fraction of the farm that is heavily degraded. Climate change is implemented by applying different rates of rainfall reductions. The graph shows the area, which is considered to be in a degraded state over time for the optimal management approach under a baseline and three climate-change scenarios. Results show that optimal management strategies comprise a certain level of ecological sustainability even though the amount of rainfall is reduced due to climate change. Only in the extreme scenario with an unlikely reduction of precipitation by 30% is it economically favourable to end up with a high fraction of the farm being in a degraded state.

In summary these results show, that ecological sustainability and economic success of a business are not necessarily contradictory. More detailed results for analyses of other management options and scenarios can be found in Article III.7.5 and in Buß (2006).

Integrated study 2: sustainable landuse on resettlement farms in the Omaheke Region in Namibia

Our second example is a study that was conducted in 2009 in the Omaheke Region at the eastern border of Namibia. This study aimed at identifying key problems of and revealing possible strategies for farmers that are farming on land that was redistributed as part of the Namibian Land Reform process. In this chapter we want to show how the economic output of a farm can be improved by applying more adaptive and moderate stocking strategies and that ecological and economic preferences need not necessarily be contradictory.

The study included three parts: 1) an economic survey including semi-structured interviews that identified the key socio-economic parameters of the resettlement farms (e.g. size of the farm, costs, income, indebtedness, ethnic background, number of livestock, etc.); 2) an agro-ecological estimation of range condition according to a standardised method of Zimmermann (2009) in order to quantify the ecological situation on the farms; and 3) an agent-based ecological-economic model of a livestock production farm. The details concerning the design and results of parts one and two can be found in Article III.5.3.

The ecological-economic model is based on an economic model for a single livestock producing farm and a well-established, eco-hydrological model (EcoHyd, Tietjen et al. 2009a) that was parameterised for typical soils and precipitation in the study region (see Article III.7.2) as well as on an agent- and rule based model simulating cattle herd dynamics, costs, profits and animal condition. The data that were needed to parameterise the model was taken from the survey mentioned above, so that the model simulations are representative for an average resettlement farm in the study region.

The model was designed so that it could also serve as a training tool (see Article III.7.6). A first version of the tool (and thus also of the model) was presented in pre-tests to resettlement farmers in advance, so that their feedback could be included in the model version that is presented here. However, in this chapter we present results of recently-repeated 50-year simulations with different, stochastic rainfall time-series. Results presented here are derived from simulations of a 3,000 ha farm producing cattle. We compared different strategies regarding absolute stocking rate, reaction to environmental variation and biennial resting of 50% of the farm in order to identify the economic (mean annual profit) and ecological (fraction of farm that is in a degraded state at the end of the simulation) consequences for a 50 year application of the respective management schemes.

Results show that generally moderate stocking rates result in highest mean annual profits for the farming business (Fig. 28a). The highest profit, however, was generated by the application of a biennial resting strategy, with a herd size reduction to 70% of the average herd size in drought years (< 300 mm). In contrast, a strategy with a fixed herd size and no application of resting resulted in significantly lower average profits.

Interestingly, the response of the vegetation to this management shows, that a more sustainable management, where the degraded fraction of the farm is significantly lower than in the non-resting scenario, leads to a higher average profit (see Fig. 28b). This means, that the ecologically more desirable strategy (biennial resting) also reveals the economically most beneficial output. However, all scenarios that have been feasible from an economic perspective (i.e. positive mean annual profit over 50 years) lead to a significant degradation of the savanna ecosystem. The calculated maximum annual profits show that the income level of the simulated resettlement farm is very low even in the long run. This result is consistent with the survey data (see Article III.5.3), which showed even lower profits with many respondents making losses. This might be due to the influence of poorly-adapted farming practices, with higher costs than necessary, having either too many or too few livestock, or grazing on a degraded ecosystem. The ecological, on-site analyses indicated that the ecosystem is already in a degraded and below-average ecological condition. This consequently only allows for even lower stocking rates compared to the ones that were given by simulation results, since our simulations are based on an initial moderate to good condition of the veld. Hence, the present interdisciplinary study clearly shows the necessity to further deepen the understanding of the situation of resettlement farmers and to develop and implement adequate schemes for the ongoing land reform process, including more detailed management and governance options like, for example, multi-farm cooperation in combination with spatio-temporal grazing schedules.

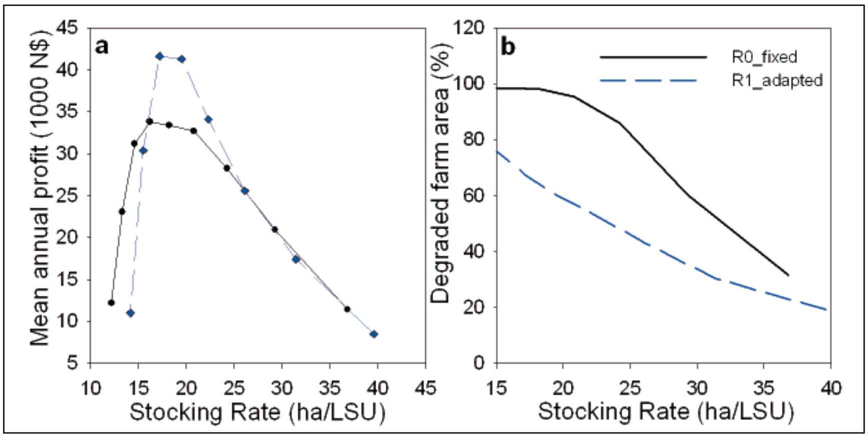

Fig. 28: Effects of stocking rates. a) Mean annual farm profit (N$1,000) and b) mean fraction of rangeland that is in a degraded state (%) of repeated 50 year simulations of a 3,000 ha resettlement farm in the Omaheke region in dependent of the average long term stocking rate (ha/LSU) for a fixed herd size scenario with no resting (R0_fixed) and a strategy that adapts herd size to droughts and applies a biennial resting (R1_adapted).

2.7 Recommendation for landusers and conservation planners

Relevance of fire management for bush control

[D.F. Joubert]

In historic times, rangeland utilisation by game, livestock, and pastoralists in Namibia was constrained by available perennial surface water. This allowed sufficient rest for the grasses. As a consequence the grass sward was dominated by vigorously-growing perennial grasses. Fires were more frequent, usually coinciding with the establishment of encroaching shrubs particularly in years of high rainfall, thus maintaining an open savanna structure. In areas where natural perennial water occurred, such as around natural fountains, continuous grazing prevented extensive fires from occurring, and in some cases is likely to have resulted in encroachment, as witnessed by explorers as far back as the 1850s (Andersson 1856). Within the last century, boreholes and waterpoints have effectively made surface water available throughout the year and throughout the savannas, thus allowing sedentary game and livestock populations to graze more or less continuously. Grasses did not have a sufficiently long rest period to recover, which has resulted in earlier successional stage species to dominate, as well as a lower fuel load to build up. This in turn has resulted in a reduction in the number of fires. This reduction of fuel load, along with the deliberate exclusion of fire, has resulted in the periodic successful recruitment of woody shrubs on a landscape scale.

The exclusion of fire has been largely responsible for the transition of open savanna to shrub dominated savanna at critical times (Fig. 30). *Acacia mellifera* subsp. *detinens* has probably only undergone mass recruitment around six times in the Highland Savanna (adjacent to the Thornbush Savanna) since rainfall records in 1892 (Joubert et al. 2008a). This would also reflect the situation in the Thornbush Savanna. Despite the few chances for recruitment, *A. mellifera* is dominant in the landscape in most of the Thornbush Savanna. *A. mellifera* only produces seeds en masse during times of particularly high rainfall. This needs to be followed directly by at least another season of high and evenly spread rainfall to ensure establishment (Joubert et al. 2008a). This is because seeds germinate easily and thus seed banks are ephemeral (Joubert et al. 2008a). Field observations suggest that a month of almost daily effective rain, just prior to the seeds having fallen, as was witnessed in January 2010, allows seedling establishment, even in average rainfall years. Early evidence from BIOTA research shows that competition with climax grasses has little effect on seedling vigour, but that fire may completely prevent an establishment event.

Rangeland managers need to consider applying well planned fires during times of *A. mellifera* establishment. Fortunately, conditions for establishment coincide with ideal conditions for burning since high rainfall events produce good fuel loads provided the veld is well rested. Based on the frequency of recruitment events, a farmer is likely to only need to burn each portion of land every 20 years or so (Joubert et al. 2008a). Slight decreases in productivity in the season following a burn are more than offset by the long term maintenance of high grass production due to the prevention of shrub encroachment. Decision support

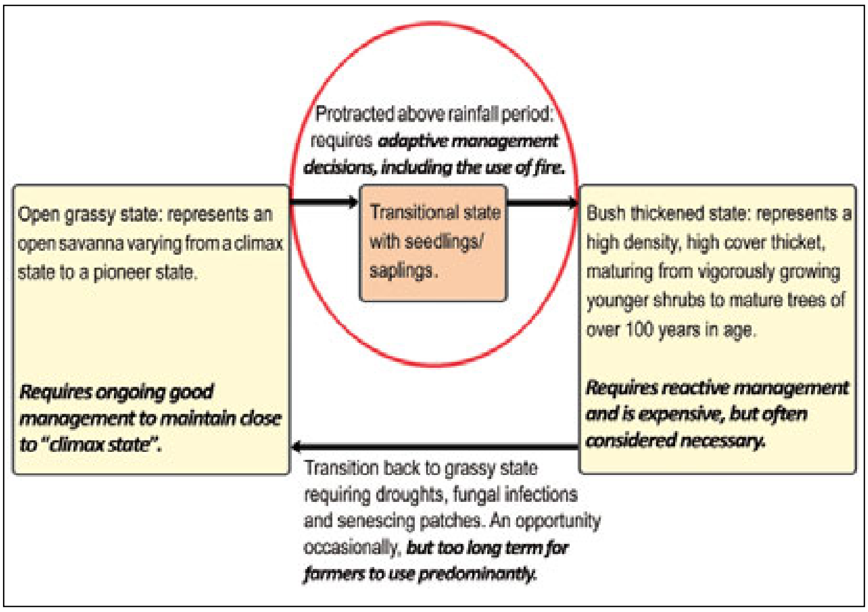

Fig. 29: A simplified version of the conceptual state-and-transition model for Thornbush Savanna.

systems such as wikiChameleon (Joubert et al. 2008b, 2009) are useful in assisting farmers in taking decisions regarding shrub encroachment. This is described in Article III.8.5.

Identification of key/indicator species for vegetation states—input for land managers to evaluate the ecological condition of their rangelands

[M. Strohbach]

The absolute definition of vegetation states according to species composition and the percentage cover of such species will remain problematic in the Namibian Thornbush Savanna, as both variables are, apart from rangeland management practices, strongly influenced by the timing of rainfall and soil type, especially at the soil surface.

Co-occurrence analysis with the software packages EcoSim and COOC, together with the analysis of Plant Functional Types (PFT's) showed that species interactions in the savanna are much more complex than those that exist between shrubs and grasses only. Different types of grasses, for example, are also strong competitors, and this is strongly influenced by grazing—not just overgrazing, but also selective grazing that occurs during the under-utilisation of the veld. From preliminary results it can be assumed that the dynamics of the herb layer strongly influences the stability of the topsoil. The loss of topsoil further influences the persistence of herbaceous species, and their loss may enable more shrubs to become established. Shrubs, in turn, have a major influence on the persistence and composition of herbaceous species. However, this is not just dependent on shrub density alone, but also on the height and actual shape of the shrubs. This can be seen in Figs. 30 and 31, which show a principal component analysis of grass, and sedge PFT's, together with a second habitat matrix.

To evaluate the ecological condition of rangelands, a practice of annual fixed-point monitoring over several years must be followed as a single year evaluation will be misleading. The three variables that will need to be monitored are: species composition (simplified with the use of PFT's), the percentage cover of these PFT's as well as soil surface condition. The most suitable method for such monitoring is the Landscape Function Analysis (LFA) approach along transects, but incorporating PFT's to describe the vegetation more accurately. Very importantly, the LFA needs to be conducted during the dormant season, which in the Namibian Thornbush Savanna is from July to August. The variables that will give the best indication as to the deterioration or regeneration of rangelands are as follows:

- Shrub cover: Whether thorny or non-thorny, a sudden increase in young shrubs less than 60–70 cm in height, indicates a definite ongoing degeneration of the veld. It is at this time that active intervention against the shrub cover must be undertaken, as this is the stage where shrub/grass dynamics undergo their first relatively significant and usually irreversible changes. A high cover of tall shrubs will result from a long period of continued, unchecked degradation, and is usually associated with a considerable loss of original topsoil as well as the seed banks that were present in these topsoils.
- Types and cover of perennial grasses: The most productive veld has a relatively high and diverse (i.e. more than two species) cover of perennial grasses with very dense basal tufts and either very fine leafy culms and non-spiny seeds (e.g. *Stipagrostis uniplumis*), or short culms with long, relatively broad leaves and only the flower-bearing culms being relatively thick (e.g. *Brachiaria nigropedata*). A first sign of degradation may be the gradual increase of perennial grasses that either have a strong tuft with relatively thick, leafy culms or very low, small tufts with many long flowering culms bearing spiny florets (e.g. *Aristida congesta*). A low cover of perennial grasses overall will indicate that the veld is most likely prone to future shrub encroachment or it is at risk of becoming completely degraded.
- During the growing season, the type and amount of annual grasses and herbs may also give an indication of veld condition. Should the veld be dominated by one or two specific species of annual grasses or herbs, this may be an indication of how the rain has been distributed in that particular year. If, however, a similar dominance of annual species is present every year, especially weedy species such as *Tribulus* spp., *Tagetes* spp., or bulbous species, or when annual grass and herb species are far more common than desirable perennial grasses, then this indicates that the veld is relatively degraded and has a low productivity.

Fig. 30: The association of different grass and sedge Plant Functional Type (PFT) groups with the percentage cover of tall shrubs (mostly Acacia mellifera subsp. detinens), as shown by PCA. Within each PFT group, only a few species actually prefer a high cover of tall shrubs as indicated by a reduction in the size of the symbol. Thus, as shrub cover increases, most grass species disappear.

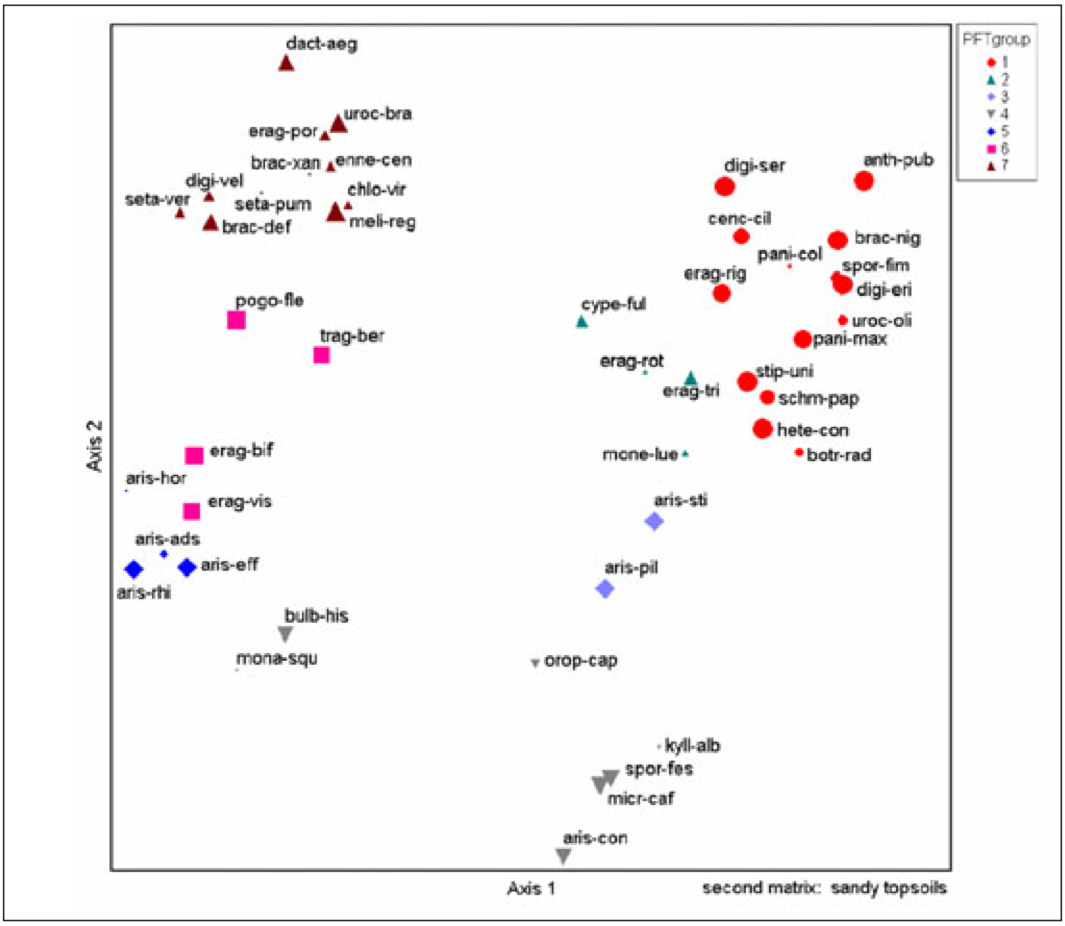

Fig. 31: The association of different grass and sedge PFT groups (the same as in Fig. 30) with soil surface texture and in particular, the dominance of sandy topsoils. Only a very few species actually prefer loamy topsoils as indicated by a reduction in the size of the symbols.

Grazing management during droughts

[M. Strohbach]

Palatable perennial grasses appear to be more abundant and more resilient where topsoils are relatively sandy (see 'Impacts of rainfall on vegetation cover' in Subchapter IV.2.4). This has important implications for management decisions in an area. In addition, the recovery of perennial grasses, if grazed excessively during a drought period, is not nearly as rapid, within one season, as many farmers would hope, even with sufficient rainfall. This is most evident on the loamier and hydrologically less favourable soils. Therefore, erosion of sandy topsoils should be prevented as far as possible, either through the rapid reduction of stocking rates during years of drought or by avoiding extensive grazing in those camps, which possess a high cover of palatable grasses. Most important, however, is that long-term stocking rates for an area should be determined according to the average availability of grazing biomass during the dormant season and not during the peak growing season, as is still standard practice with most framers and agricultural authorities.

Guidelines on best-practice restoration techniques in Namibia

[M. Strohbach]

Restoration experiments carried out on the Etjo Erosion plains highlighted the importance of the following best practices restoration techniques:

- It is imperative that the landuser understands what is happening in the field and is able to provide answers to questions such as: Is there sheet erosion? Does rainwater infiltrate easily or does the majority run off and if so, in which direction? What type and how much perennial grasses are there? What other vegetation, if any, is there in the camps?
- For any effort for veld regeneration, it is much more viable to create many smaller, 'fertile islands' comprised of strips of about 50 m by 3–5 m, that are distributed throughout a camp or farm, rather than to try and restore an entire continuous area. During adverse years, a mosaic of runoff and run-on-patches will remain much more resilient than uniformly homogenous areas with only a low cover of plants.
- Soils that are bare and unvegetated usually have a relatively thick, impenetrable upper layer that often forms an ecological barrier to the establishment of plants. This layer needs to be ripped open to at least 25 cm depth, preferably more. It will be more effective to do few, deep rips with a single ripping implement than many shallow rips.
- No matter how flat the area appears to be, it is advisable to always rip along a slight contour, with the lowest point in the direction of the water runoff. In this manner resources such as soil, seed and organic matter, which are washed off bare areas become trapped and accumulate to help enrich the restored patches, which can then grow bigger by themselves over time.
- Often, it may be necessary to sow in seeds of perennial grass species. It may be possible to purchase some seeds, but then it is advisable to use species always that occur naturally in the area. Road verges are usually a good source for collecting seeds. However, since all grass seeds have an inherent dormancy of 7–10 months, they should be collected during the season prior to when the ripping takes place.
- Timing: rip early in the growing season, preferably just after and within days of the first rains (> 5 mm). If you sow in grass, do so very sparingly to avoid creating patches of preferential grazing. After sowing loosely, cover the seeds with cut bushes to protect the seedlings from being grazed during the first year.

Summary of recommendations for farmers

[I. Zimmermann & G.N. Smit]

Estimation of grazing capacity

Due to the fluctuating nature of Namibia's climate, it is essential to include provision of a drought reserve when estimating the grazing capacity of the rangeland. If the stocking rate needs to be reduced, the best time to do so for the benefit of rangeland condition and animal performance is at the start of the dry season, although seasonal changes in price may sometimes warrant holding on to animals for longer. If the stocking rate can be raised after a drought, it may be helpful to wait until perennial grasses have had an opportunity to regain vigour before increasing the stocking rate. It is recommended that farmers who have not yet gained experience in estimating the grazing capacity by visual judgement should initially apply a quantitative method such as that of van Wyk (1988) before progressing to the use of reference photographs (Klintenberg et al. 2007).

Provision of rest

Periods of absence should ideally be flexible so that they may be adjusted by adaptive management. The condition of grass in the destination paddock provides a more valuable indicator of when to move, for the health of the grass, than the condition of grass where livestock are currently grazing, although the latter may have a greater impact on animal performance. If periods of absence during the growing season need to be fixed in advance, then longer periods are better than shorter periods, during which time there might not be enough rain for grazed grasses to regain vigour. Annual resting, such as proposed by Dames (2009), may hold promise as a simple grazing strategy that cares for both rangeland and animal condition. Where farmers have insufficient fenced paddocks for provision of adequate rest, they could combine their herds with neighbours and rotate through all their paddocks (Kruger 2008) or apply herding on unfenced land (Kangombe & Kapi 2008).

Trampling

Farmers should pay close attention to the effects of trampling on their farms, in different seasons and on different soils, to determine whether it could be applied to help certain parts of their rangeland. They need to bear in mind that long rest should be provided after trampling and that animal performance will be sacrificed to some extent.

Burning

Farmers should also determine whether the occasional use of controlled burning could help a portion of their rangeland, whether for the control of bush saplings, the rejuvenation of perennial grass, or the creation of nutrient hotspots. If fire is considered helpful, then the conditions required for successful burning will either need to be in place, waited for or encouraged to develop, such as sufficient fuel and sufficient residual water and organic matter in the soil.

Bush control

It is recommended that farmers consult the decision support system (Joubert et al. 2009) accessible at: http://chameleon.polytechnic.edu.na/wiki/. This should preferably be to prevent bush encroachment from taking place, by applying management closer to the root causes in a diagnostic problem tree (Zimmermann et al. 2008). However, in cases where the symptom of bush encroachment needs to be treated, the decision support system mentioned above provides links to a data base of experiences by Namibian farmers (Barac et al. 2004). If arboricides are to be used, the risk of killing non-target bushes and trees should be minimised.

Ground water

Management of ground water, from where most farmers obtain drinking water for their animals, is crucial for the sustainability of farming. It is recommended that farmers monitor their ground water levels and, where they are found to be lowering, farmers should consider taking action to recharge the aquifer such as reducing bush cover (Bockmühl 2009) or aligning roads towards recharge sites.

Parasite control

To avoid harming non-target organisms, such as dung beetles, that provide essential ecological services for rangeland and animal health, farmers should control parasites without, or with minimal use of, toxic chemicals. Those who are unable to apply rotational grazing to disrupt parasite life cycles, and those who are still forced to kraal their animals at night, could at least try non-toxic treatments or chemicals that result in minimal harm to dung beetles, while at the same time making an effort to eliminate animals with high parasite loads from the herd.

Vision of achievable rangeland condition

Due to the fluctuating nature of Namibia's climate, the condition of even the best rangeland changes annually. It is useful for farmers to know what condition of rangeland is achievable under the prevailing climatic conditions. Such a vision could be provided by a benchmark site, where the same overall stocking rate as the surrounding area is applied twice a year, followed by long periods of absence. It is therefore recommended that farmers establish small benchmark sites for their rangeland so that they may differentiate between the effects of climate and management. Apart from providing the farmer with information upon which to base management decisions, the benchmark may serve as a source of seed of good grass species, for spreading out into the surrounding rangeland.

Financial management

Farmers could benefit by examining their financial records, to determine whether their expenses are justified, if they are not already doing so. If farmers focus on reducing non-essential expenditure they are likely to increase profitability (von Alten 2008). Before making any new investment it is recommended that farmers perform cost-benefit analyses on the intended investment and on alternatives, to determine which brings the best returns per dollar spent, especially when those dollars need to be repaid at interest. Reliance on overstocking to increase profitability provides only short-term relief, as the resulting reduction in carrying capacity limits this option for the future. Farmers who obtain poor prices for their products should seek alternative markets, including those that pay premium prices for "green" products raised on natural rangeland.

Monitoring

It is also recommended that farmers undertake more formalised monitoring together with record keeping of their rangeland. This could be as simple as taking regular fixed point photographs at labelled sites and perhaps estimating abundances of bushes and grasses at regular intervals. Those who are more adventurous could back up the visual impressions with measurements. Farmers who co-operate with neighbours to form study groups can benefit by the sharing of information and joint monitoring of their test sites.

Benefiting from spatial heterogeneity

Farmers should exploit the spatial heterogeneity that occurs within their farms, and consider movements of livestock off the farm at critical periods. Fynn (2009) proposed the re-introduction of transhumance pastoral migrations between natural wet and dry season grazing areas where unfenced land still exists. In situations where land subdivision is irreversible, he proposed cooperation between neighbouring farmers to jointly manage their herds over larger areas, such as the practice of agistment applied by some Australian farmers (McAllister et al. 2006).

Conservation of biodiversity

[N. Blaum, A. Horn, F. Jeltsch, E. Rossmanith, R. Simmons & C. Seymour]

BIOTA results in Thornbush Savanna rangelands show that grazing induced shrub encroachment threatens species diversity of plants and animals across taxonomic groups (details are described in Subchapter IV.2.4). Nevertheless, grazing is not negative for species diversity per se. On the contrary, in Kalahari Thornbush Savanna rangelands for example, moderate livestock grazing has been shown to have a positive effect on species richness of different arthropod taxa, rodents, and small and medium sized carnivores (e.g. Blaum et al. 2007a, b, c, 2009a, b). This is an important finding for both rangeland managers, and conservation planners. In particular, when planning shrub removal programs that aim to increase grazing capacity, some shrubs should be kept to sustain species diversity in Thornbush Savanna rangelands. Although single shrubs do not comprise hot spots of species diversity they serve key functions for many plant and animal species as they provide shade, shelter and may also serve as nest sites for some bird species (for details see Subchapter IV.2.4).

A key finding for sustaining bird diversity in arid Namibia was that land managers and conservation managers should reduce the extent of bush thicket areas and conserve all dry riverlines. Bird diversity decreased in bush thickets while open (grassy) areas showed marginal declines and dry riverlines showed no declines in avian richness (see ‘Identifying key patterns’ in Subchapter IV.2.4 for details). This indicates that sensitive riparian environments are key habitats sustaining bird diversity. Furthermore, given that birds appear to be attracted to tall trees across all savanna types (Kaphengst & Ward 2008, Seymour & Dean 2009), land managers are encouraged to retain the taller trees when thinning bush-encroached areas. This would not only benefit biodiversity but would also provide shade for livestock and contribute to nutrient cycling processes within rangelands soils.

2.8 Future research needs

Background

[F. Jeltsch, N. Blaum, E. Rossmanith, D. Lohmann, D.F. Joubert, I. Zimmermann, R. Simmons, C. Seymour, C. Grohmann, A. Horn, C. Reisch, P. Poschlod, M. Strohbach & D. Wesuls]

BIOTA research has significantly improved our understanding of how populations, communities, and biodiversity may respond under different landuse options and climate change scenarios in African Thornbush Savannas. The key scientific results and simulation models were further developed into several educational and management tools for rangeland management and biodiversity research (compare Article III.7.6). On this basis, we identified three major topics for future research needs, which require inter-, but particularly transdisciplinary approaches: (i) linking dynamics landscapes with biodiversity dynamics, (ii) understanding the impacts of landuse options and climate change on ecosystem functions and services (EF&S), and (iii) restoration of degraded savanna rangelands.

Linking dynamic landscapes with biodiversity dynamics

A next crucial step in biodiversity research in Thornbush Savannas is the development of a mechanistic understanding of biodiversity dynamics under the coupled effects of landuse and climate change within a dynamic savanna landscape. For example, dry riverlines support higher bird diversity and riparian vegetation habitats are at least 3°C cooler at midday than surrounding bush-encroached and grass-dominated savanna habitats (Seymour & Simmons 2008) (see ‘Identifying key patterns’ in Subchapter IV.2.4). Although this clearly indicates the importance of conserving riverine habitats for sustaining bird diversity, the dynamics of habitat mosaics and bird diversity remains unclear and makes solid management recommendations difficult.

Although biodiversity can play a crucial role for ecosystem functioning, the effects of spatio-temporal changes in biodiversity pattern on ecosystem functions in changing landscapes are largely unknown (Lundberg & Moberg 2003, Srivastava & Vellend 2005, Duffy et al. 2007, Cardinale et al. 2009). In particular, migration and spatial avoidance are key features of adaptation to highly frequent disturbances in anthropogenic landscapes.

Land management that largely differs in space and time will affect biodiversity at different trophic levels with implications for trophic interactions. For example, climate or landuse impacts can affect predator densities and foraging strategies that are characterised by predator-specific animal movements. Such changes in predator densities or movement behaviour for foraging are likely to modify the abundance of small mammals, dung beetles etc., which provide tunnel systems and perturb the soil and may affect ecosystem functioning by, for example, changing infiltration rates. Another example is the spatial-temporal change in the diversity of pollinators, which provide important ecosystem services.

A mechanistic understanding of biodiversity dynamics, trophic interactions, and their consequences for ecosystem functioning (see below) requires the explicit consideration of dynamic landscapes, vegetation and landuse patterns at different scales and most importantly the simultaneous investigation of multiple interacting species or functional types. This approach will allow for the identification and testing of land management options, which support the functioning of healthy ecosystems and which are adapted to the predicted changes in climate.

Understanding the impacts of landuse options and climate change on ecosystem functions and services (EF&S)

Rangeland degradation in south-western Africa is significant and in Namibia alone about 50% of the savanna areas are purportedly affected (Bester 1998). A variety of savanna studies have analysed the available options to stabilise or restore specific ecosystem services by sustainable land-management systems and appropriate governance arrangements. In most studies the main focus is either on the impact of land degradation on forage and livestock productivity (e.g. Hudak 1999, Briske et al. 2008) or on biodiversity (e.g. Richardson 1998, Blaum et al. 2007a, b, c, 2009a, b). However, there is a lack of studies, which focus simultaneously on multiple EF&S, and only a very limited understanding exists of the trade-offs between different socio-economic and ecological management options and aims. For example, the build-up of woody biomass supports an increase in carbon stocks and thus a reduction in global greenhouse gas emissions (Grace et al. 2006). On the other hand area-wide bush encroachment causing a significant reduction of economic profitability (e.g. livestock production) (Grace et al. 2006), and biodiversity (Richardson 1998, Blaum & Wichmann 2007, Blaum et al. 2007a, 2009a, b). Furthermore, the increase of woody vegetation can alter the regional water balance by increasing evapotranspiration and reducing groundwater recharge (Simioni et al. 2003). This clearly shows the strong trade-off between provisioning services such as livestock production and regulating ecosystem services such as carbon sequestration and groundwater recharge and biodiversity. It also shows the scale-dependence of competing services and related stakeholder interests with local and the shorter-term interest of farmers involved in livestock production and global and longer-term benefits evident in carbon sequestration.

The global character of externalities requires global governance instruments of benefit-sharing and compensation. However, it remains unclear as to how landuse optimisations towards either direction may affect other ecosystem services and their complex interdependencies. A similar trade-off exists for farmers who rely on income from wildlife species. The management of endemic wildlife for hunting, meat production and ecotourism (Barnes & de Jager 1996, Rao & McGowan 2002) becomes an increasingly important landuse option and is also assumed to contribute to the control of undesirable growth of woody species (McGranahan 2008). However, when wildlife populations increase to unsustainable levels as observed, for example, on many private lands in Namibia where there has been an increase of approximately 70% between 1972 and 1992, the risk of overutilisation of grazing or browsing resources increases significantly (McGranahan 2008).

Future landuse options also include the production of biofuels in the form of fuel wood and charcoal production, which is suitable for marginal lands (Koiwang 2000). The removal and use of undesired woody vegetation for energy production can contribute to the restoration of degraded areas for future livestock production, but it is unclear what effects it has on other services such as soil quality, carbon sequestration as well as on biodiversity. It is also not known whether such practices are sustainable in the long term, especially given the fact that growing urban demands might cause an overutilisation of all types of woody vegetation including ecologically-important trees (Arnold et al. 2006).

Setting the right incentives for ecosystem management, which maximises the equal distribution of welfare and benefits at local, national and global levels, requires a good understanding of the costs and benefits experienced by different stakeholders. Current behaviour is adapted to market mechanisms such as prices and capital access, as well as formal and informal social rules. Too often prices do not cover all the costs associated with landuse impacts such as the costs that are put on current neighbours and on future generations through the impact of different landuse practices on EF&S. If prices for resource use are too low, overutilisation is to be expected (compare Worldbank 2008).

The extent of this overexploitation depends on additional factors. Tenure systems have an influence by assigning property rights and, thus, allotting personal interests in current and future returns to different landuse options and intensities. In addition, tenure systems determine who is making actual decisions and this results in system-dependent learning curves, which in turn may influence future landuse options (Popp et al. 2009b). The social organisation of families and local units also determines the extent to which future generations are included in decision-making processes.

Restoration of degraded savanna rangelands

Efforts to restore shrub encroached land in Namibia are escalating, yet the impacts of these measures on biodiversity and ecosystem functioning have largely not been tested (Joubert & Zimmermann 2002). There is thus an urgent need to focus research on the impacts of different restoration measures and strategies on biodiversity and ecosystem functioning.

From a rangeland manager's perspective, bush encroachment reduces livestock production. For example, an estimated N$700 million per year of beef production has been lost in Namibia due to a decline in rangeland grazing potential (de Klerk 2004) and by 2009, this figure has likely doubled. Bush encroachment also negatively affects other ecosystem functions and services, such as the replenishment of groundwater, forage production and biodiversity (Barnard 1998; see also previous chapters and compare Article III.7.3). On the other hand, however, bush thicket patches in a matrix of open savanna can also provide important functions for biodiversity and soil quality (Mills & Fey 2004) and landscape scale bush thickets were already a feature of the landscape in the 1800s (Andersson 1856). Concerns over the economic costs of bush encroachment have led to widescale clearing in the focal area (van den Berg & Kellner 2005), along with the utilisation of the cleared wood, particularly for charcoal. The demand for wood for other products, including electricity is increasing rapidly.

However, the impacts of bush control on ecosystem functions and services have not been adequately analysed, nor has the sustainable success of debushing strategies been monitored and achieved as yet. In order that future restoration is both economically and ecologically sustainable and truly restorative, and not damaging to ecosystem functions and services, this lack of documented information needs to be addressed. In addition, innovative restoration techniques, such as the manipulation of soil chemical and physical properties including soil nutrient levels, need to be evaluated experimentally. The edaphic drivers of bush encroachment are largely unknown, thus there is a need to research the differences in soil properties between bush-encroached landscapes and those that are not bush-encroached. The implementation and adoption of Bush Expert (Barac et al. 2004) and other Decision Support Systems (DSS), such as wikiChameleon (Joubert et al. 2008b) is limited due to a lack of awareness and training opportunities. A consolidation and coordination of existing DSS approaches is likely to facilitate this sustainable development. Such approaches could be supported by best practice demonstration sites, where successful farmers show how they achieve good rangeland condition and buffer drought. In this way, other farmers could be encouraged to apply such strategies.

Bush encroachment is largely related to poor grazing management, which may include both under or overgrazing (e.g. Roques et al. 2001). Sustainable restoration of bush-encroached areas, however, cannot be undertaken if the root cause of bush encroachment is not addressed. Over the last 100 years Africa has switched from dominantly large-scale migratory grazing to small-scale sedentary or ranch-style grazing (Fryxell & Sinclair 1988). The scale at which grazing occurs has large effects on grassland productivity with small-scale ranches generally exhibiting a decrease grassland productivity and large-scale migratory grazing exhibiting an increase grassland productivity over time (Milchunas & Lauenroth 1993, Frank et al. 1998). Moreover, it has been demonstrated that grazing cattle at the same stocking rate but changing the scale at which they graze a particular area through the manipulation of herd size, density, and movement, for example, can result in dramatically different effects on grassland composition and woody encroachment (Fuhlendorf & Engle 2004, Zimmerman & Smit 2008). This is consistent with the prediction that scale may provide a unified understanding of the response of various ecosystem properties to some environmental influence (Sandel & Smith 2009). A deeper understanding of the influence of the scale of grazing management on the tree/grass balance is important.

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References

Ainsworth, E.A., Long, S.P. (2005): What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. – New Phytologist **165**: 351–371.

Alten, V. von (2008): Decision making for emerging commercial farmers. – Proceedings of the 12th Namibian Rangeland Forum. CD-ROM.

Andersson, C.J. (1856): Lake Ngami; or explorations and discoveries during four years wanderings in the wilds of South Western Africa. – London: Hurst & Blacket Publishers.

Anderson, M.D., Anderson, T. (2001): Too much, too quickly – doubts about the sustainability of the Camelthorn wood harvest. – African Wildlife **55**: 21–23.

Arnold, J.E.M., Köhlin, G., Persson, R. (2006): Woodfuels, livelihoods, and policy interventions: changing perspectives. – World Development **34**: 596–611.

Barac, A., Kellner, K., Klerk, N. de (2004): Land user participation in developing a computerised decision support system for combating desertification. – Environmental Monitoring and Assessment **99**: 223–231.

Barnard, P. (1998): Biological diversity in Namibia: a clash of sea and land, fog and dust. – Biodiversity and Conservation **7**: 415–417.

Barnes, J.I., Jager, J.L.V. de (1996): Economic and financial incentives for wildlife use on private land in Namibia and its implication for policy. – South African Journal of Wildlife Research **26**: 37–46.

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.

Bester, F.V. (1998): Major problem – bush species and densities in Namibia. – Agricola **10**: 1–3.

Blaum, N. (2008): Seasonal differences in spatial distribution of small carnivores in fragmented savannah landscapes. – African Journal of Ecology **46**: 702–705.

Blaum, N., Wichmann, M. (2007): Short term transformation of matrix into hospitable habitat facilitates gene flow and mitigates fragmentation. – Journal of Animal Ecology **76**: 1116–1127.

Blaum, N., Rossmanith, E., Popp, A., Jeltsch, F. (2007a): Shrub encroachment affects mammalian carnivore abundance and species richness in semiarid rangelands. – Acta Oecologica **31**: 86–92.

Blaum, N., Rossmanith, E., Schwager, M., Jeltsch, F. (2007b): Responses of mammalian carnivores to land use in arid savanna rangelands. – Basic and Applied Ecology **8**: 552–564.

Blaum, N., Rossmanith, E., Jeltsch, F. (2007c): Land use affects rodent communities in Kalahari savannah rangelands. – African Journal of Ecology **45**: 189–195.

Blaum, N., Engeman, R.M., Wasiolka, B., Rossmanith, E. (2008): Indexing small mammalian carnivores in the southern Kalahari, South Africa. – Wildlife Research **35**: 72–79.

Blaum, N., Seymour, C., Rossmanith, E., Schwager, M., Jeltsch, F. (2009a): Changes in arthropod diversity along a land use driven gradient of shrub cover in savanna rangelands: identification of suitable indicators. – Biodiversity and Conservation **18**: 1187–1199.

Blaum, N., Tietjen, B., Rossmanith, E. (2009b): The impact of livestock husbandry on small and medium sized carnivores in Kalahari savannah rangelands. – Journal of Wildlife Management **73**: 60–67.

Blondel, J. (2003): Guilds or functional groups: does it matter? – Oikos **100**: 223–231.

Bockmühl, F. (2009): Evidence of impact of bush encroachment on groundwater resources. – Proceedings of the 13th Namibian Rangeland Forum, Windhoek 27-29 October 2009: 6.

Bond, W.J., Midgley, G.F. (2000): A proposed CO_2-controlled mechanism of woody plant invasion in grasslands and savannas. – Global Change Biology **6**: 865–869.

Bond, W.J., Midgley, G.F., Woodward, F.I. (2003): The importance of low atmospheric CO_2 and fire in promoting the spread of grasslands and savannas. – Global Change Biology **9**: 973–982.

Bothma, J. du P., Rooyen, N. van, Rooyen, M.W. van (2004): Using diet and plant resources to set wildlife stocking densities in African savannas. – Wildlife Society Bulletin **32**: 840–851.

Bowman, J. (2003): Is dispersal distance of birds proportional to territory size? – Canadian Journal of Zoology **81**: 195–202.

Briske, D.D., Derner, J.D, Brown, J.R., Fuhlendorf, S.D., Teage, W.R., Havstad, K.M., Gillen, R.L., Ash, A.J., Willms, W.D. (2008): Rotational grazing on rangelands: reconciliation of perception and experimental evidence. – Rangeland Ecology and Management **61**: 3–17.

Buß, H.J. (2006): Land use options of Namibian farms. Optimal management strategies proposed by bioeconomic models. – Agrarökonomische Studien **26**. Kiel: Wissenschaftsverlag Vauk.

Buxton, R.D. (1981): Termites and the turnover of dead wood in an arid tropical environment. – Oecologia **51**: 379–384.

Calder, W.A. (1984): Size, function, and life history. – Cambridge: Harvard University Press.

Cardinale, B.J., Hillebrand, H., Harpole, W.S., Gross, K., Ptacnik, R. (2009): Separating the influence of resource 'availability' from resource 'imbalance' on productivity–diversity relationships. – Ecology Letters **12**: 475–487.

Christelis, G., Struckmeier, W. (2001): Groundwater in Namibia: an explanation of the hydrogeological map. – Windhoek: Department of Water Affairs/Geological Survey Namibia.

Cornelissen, J.H.C., Lavorel, S., Garnier, E., Diaz, S., Buchmann, N., Gurvich, D.E., Reich, P.B., Steege, H. ter, Morgan, H.D., Heijden, M.G.A. van der, Pausas, J.G., Poorter, H. (2003): A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. – Australian Journal of Botany **51**: 335–380.

Dames, C.J. (2009): The controlled fodder flow grazing management strategy (Dames, 1996) and "grass fed beef production": a sustainable, proven, environmentally friendly, extensive animal production model for the semi-arid and arid environments of southern Africa. – Proceedings of the 13th Namibian Rangeland Forum, Windhoek 27-29 October 2009: 19.

Dean, W.R.J., Milton, S.J., Jeltsch, F. (1999): Large trees, fertile islands, and birds in arid savannas. – Journal of Arid Environments **41**: 61–79.

Dore, M.H.I. (2005): Climate change and changes in global precipitation patterns: what do we know? – Environment International **31**: 1167–1181.

Drake, B.G., Gonzàlez-Meler, M.A., Long, S.P. (1997): More efficient plants: a consequence of rising atmospheric CO_2? – Annual Review of Plant Physiology and Plant Molecular Biology **48**: 609–639.

Duffy, J.E., Cardinale, B.J., France, K.E., McIntyre, P.B., Thébault, E., Loreau, M. (2007): The functional role of biodiversity in ecosystems: incorporating trophic complexity. – Ecology Letters **10**: 522–538.

Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R., Mearns, L.O. (2000): Climate extremes: observations, modeling, and impacts. – Science **289**: 2068–2074.

Engert, S., Jury, M. (1997): Sommerniederschläge im Norden Namibias. Vorläufige Ergebnisse einer zirkulationsdynamischen Untersuchung. – Würzburger Geographische Arbeiten **92**: 285–301.

Ericson, S.H., Watson, H.K. (2009): The sustainability of southern African savannas. – Environmental Science & Policy **12**: 1–4.

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.

Frank, D.A., McNaughton, S.J., Tracy, B.F. (1998): The ecology of the earth's grazing ecosystems. – Bioscience **48**: 513–521.

Fryxell, J.M., Sinclair, A.R.E. (1988): Causes and consequences of migration by large herbivores. – Trends in Ecology & Evolution **3**: 237–241.

Fuhlendorf, S.D., Engle, D.M. (2004): Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. – Journal of Applied Ecology **41**: 604–614.

Fynn, R.W.S. (2009): The scale of grazing – its influence on rangeland quality, carrying capacity and herbivore population performance. – Proceedings of the 13th Namibian Rangeland Forum, Windhoek, 27-29 October 2009: 4.

Giess, W. (1998): A preliminary vegetation map of Namibia. Ed. 3, revised. – Dinteria **4:** 1–112.

Gitay, H., Noble, I.R. (1997): What are functional types and how should we seek them? – In: Smith, T.M., Shugart, H.H., Woodward, F.I. (eds.): Plant functional types: 3–19. Cambridge: Cambridge University Press.

Grace, J., San José, J., Meir, P., Miranda, H.S., Montes, R.A. (2006): Productivity and carbon fluxes of tropical savannas. – Journal of Biogeography **33**: 387–400.

Graiff, A. (2010): Der Einfluss der Termitentaxa *Macrotermes michaelseni* und *Odontotermes* sp. (Isoptera, Macrotermitinae) auf Pflanzenwachstum und Pflanzenzersetzung in der Dornbuschsavanne Zentralnamibias. – Diplom thesis in Biology. Würzburg: University of Würzburg.

Grohmann C., Oldeland J., Stoyan D., Linsenmair K.E. (2010): Multi-scale pattern analysis of a mound-building termite species. – Insectes Sociaux. DOI: 10.1007/s00040-010-0107-0.

Guisan, A., Thuiller, W. (2005): Predicting species distribution: offering more than simple habitat models. – Ecology Letters **8**: 993–1009.

Holt, J.A., Lepage, M. (2000): Termites and soil properties. – In: Abe, T., Bignell, D.E., Higashi, M. (eds.): Termites: evolution, sociality, symbioses, ecology: 389–407. Dordrecht: Kluwer Academic Publishers.

Horn, A. (2008): Impact of different forms of land use on the vegetation of the Southern Kalahari Duneveld. – PhD thesis. Regensburg: Universität Regensburg.

Hudak, A.T. (1999): Rangeland mismanagement in South Africa: failure to apply ecological knowledge. – Human Ecology **27**: 55–78.

Hulme, M. (1992): Rainfall changes in Africa: 1931–60 to 1961–90. – International Journal of Climatology **12**: 685–699.

Jeltsch, F., Milton, S.J., Dean, W.R.J., Rooyen, N. van (1997a): Analysing shrub encroachment in the southern Kalahari: a grid-based modelling approach. – Journal of Applied Ecology **34**: 1497–1509.

Jeltsch, F., Milton, S.J., Dean, W.R.J., Rooyen, N. van (1997b): Simulated pattern formation around artificial waterholes in the semi-arid Kalahari. – Journal of Vegetation Science **8**: 177–189.

Jeltsch, F., Tietjen, B., Blaum, N., Rossmanith, E. (in press): Population and ecosystem modeling of land use and climate change impacts on savanna dynamics. – In: Hill, M.J., Hanan, N.P. (eds.): Ecosystem function in savannas: Measurement and modeling at landscape to global scales. Boca Raton: CRC Press.

Joubert, D.F., Rothauge, A., Smit, G.N. (2008a): A conceptual model of vegetation dynamics in the semiarid highland savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. – Journal of Arid Environments **72**: 2201–2210.

Joubert, D.F., Zimmermann, I. (2002): The potential impacts of wood harvesting of bush thickening species on biodiversity and ecological processes. – Proceedings of the First National Forestry Research Workshop, Ministry of Environment and Tourism, Forestry **9**: 67–78.

Joubert, D.F., Zimmermann, I., Graz, P. (2008b): A decision support system for bush encroachment. – Windhoek: Polytechnic of Namibia.

Joubert, D.F., Zimmermann, I., Graz, P. (2009): A decision support system for bush encroachment. Ed. 4. – Windhoek: Polytechnic of Namibia.

Kaiser, D., Konaté, S., Lepage, M., Linsenmair, K.E. (2009): Termites as key element in soil restoration (Zaï system). – Poster. Joint Meeting of the Society for Tropical Ecology & The Association for Tropical Biology and Conservation: 27–30. Marburg, Germany.

Kangombe, D., Kapi, U. (2008): Rangeland management on communal land – Kunene region. – Proceedings of the 12th Namibian Rangeland Forum. CD-ROM.

Kaphengst, T., Ward, D. (2008): Effects of habitat structure and shrub encroachment on bird species diversity in arid savanna in the Northern Cape province, South Africa. – Ostrich **79**: 133–140.

Kefi, S., Rietkerk, M., Alados, C.L., Pueyo, Y., Papanastasis, V.P., ElAich, A., Ruiter, P.C. de (2007): Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. – Nature **449**: 213–215.

Klerk, J.N. de (2004): Bush encroachment in Namibia – Report on phase 1 of the bush encroachment research, monitoring and management project. – Windhoek: Ministry of Environment and Tourism of Namibia.

Klintenberg, P., Kruger, A.S., Seely, M. (2007): Community-driven local level monitoring: recording environmental change to support multi-level decision-making in Namibia. – Secheresse **18**: 1–6.

Kojwang, H.O. (2000): Woodfuels review and assessment: Namibia country report. – http://www.fao.org/docrep/004/x6797e/X6797E02.htm [acc. 11.6.2010].

Kraaij, T., Ward, D. (2006): Effects of rain, nitrogen, fire and grazing on tree recruitment and early survival in bush-encroached savanna, South Africa. – Plant Ecology **186**: 235–246.

Kruger, A.S. (2008): A possible model for cooperative rangeland management on resettlement farms. – Proceedings of the 12th Namibian Rangeland Forum. CD-ROM.

Lack, D. (1947): The significance of clutch-size. – Ibis **89**: 302–352.

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.

Léonard, J., Rajot, J.L. (2001): Influence of termites on runoff and infiltration: quantification and analysis. – Geoderma **104**: 17–40.

Lundberg, J., Moberg, F. (2003): Mobile link organisms and ecosystem functioning: implications for ecosystem resilience and management. – Ecosystems **6**: 87–98.

MacArthur, R.H., Wilson, O.E. (1967): The theory of island biogeography. – Princeton: Princeton University Press.

Mazía, C., Chaneton, E.J., Kitzberger, T. (2006): Small-scale habitat use and assemblage structure of ground-dwelling beetles in a Patagonian shrub steppe. – Journal of Arid Environments **67**: 177–194.

McAllister, R.R.J., Gordon, I.J., Janssen, M.A., Abel, M. (2006): Pastoralists' responses to variation in rangeland resources in time and space. – Ecological Applications **16**: 572–583.

McCarl, B.A. (2002): GAMS User Guide: 2003. – http://www.gams.com/dd/docs/bigdocs/Gams2002/mccarlgamsuserguide.pdf [11.06.2010].

McGranahan, D.A. (2008): Managing private, commercial rangelands for agricultural production and wildlife diversity in Namibia and Zambia. – Biodiversity and Conservation **17**: 1965–1977.

McNaughton, S.J. (1993): Biodiversity and function of grazing ecosystems. – In: Schulze, E.D., Mooney, H.A. (eds.): Biodiversity and ecosystem function: 361–383, New York: Springer Verlag.

Meik, J.M., Jeo, R.M., Mendelson, J.R., Jenks, K.E. (2002): Effects of bush encroachment on an assemblage of diurnal lizard species in central Namibia. – Biological Conservation **106**: 29–36.

Meyer, J., Kohnen, A., Durka, W., Wöstemeyer, J., Blaum, N., Rossmanith, E., Brandl, R. (2009): Genetic structure in the hairy-footed gerbil (*Gerbillurus paeba*): sex specific dispersal? – Mammalian Biology **74**: 478–487.

Milchunas, D.G., Lauenroth, W.K. (1993): Quantitative effects of grazing on vegetation and soils over a global range of environments. – Ecology **63**: 327–366.

Millennium Ecosystem Assessment (2005): Ecosystems and human well-being: biodiversity synthesis. – Washington D.C.: World Resources Institute.

Mills, A.J., Fey, M.V. (2004): Transformation of thicket to savanna reduces soil quality in the Eastern Cape. – Plant and Soil **265**: 153–163.

Mills, A.J., Milewski, A., Fey, M.V., Groengroeft, A., Petersen, A. (2009): Fungus culturing, nutrient mining and geophagy: a geochemical investigation of Macrotermes and Trinervitermes mounds in southern Africa. – Journal of Zoology **278**: 24–35.

Mistry, J. (2000): World savannas. Ecology and human use. – Harlow: Pearson Education.

Nyamapfene, K.W. (1986): The use of termite mounds in Zimbabwe peasant agriculture. – Tropical Agriculture **63**: 191–192.

Oliver, I., Beattie, A.J. (1993): A possible method for the rapid assessment of biodiversity. – Conservation Biology **7**: 562–568.

Ostrom, E., Gardner, R., Walker, J. (1994): Rules, games, and common pool resources. – Ann Arbor: University of Michigan Press.

Ottaviani, D., Cairns. S.C., Oliverio, M., Boitani, L. (2006): Body mass as a predictive variable of home-range size among Italian mammals and birds. – Journal of Zoology **269**: 317–330.

Petersen, A. (2008): Pedodiversity of southern African drylands. – Hamburger Bodenkundliche Arbeiten **62**: 1–374.

Polley, H.W. (1997): Implications of rising atmospheric carbon dioxide concentration for rangelands. – Journal of Range Management **50**: 561–577.

Popp, A., Schwager, M., Blaum, N., Jeltsch, F. (2007): Structural diversity predicts the occurrence of the yellow mongoose under shrub encroachment in a semi-arid savanna. – Ecological Modelling **209**: 136–148.

Popp, A., Blaum, N., Jeltsch, F. (2009a): Ecohydrological feedback mechanisms in arid rangelands: simulating the impacts of topography and land use. – Basic and Applied Ecology **10**: 319–329.

Popp, A., Domptail, S., Blaum, N., Jeltsch, F. (2009b). Land use experience does qualify for adaptation to climate change. – Ecological Modelling **220**: 694–702.

Popp, A., Vogel, M., Blaum, N., Jeltsch, F. (2009c): Scaling up ecohydrological processes: role of surface water flow in water-limited landscapes. – Journal of Geophysical Research-Biogeosciences **114**: G04013. DOI: 10.1029/2008JG000910.

Poschlod, P., Kleyer, M., Jackel, A.K., Dannemann, A., Tackenberg, O. (2003): BIOPOP- a data base of plant traits and internet application for nature conservation. – Folia Geobotanica **38**: 263–271.

Prinzinger, R. (1993): Life span in birds and the ageing theory of absolute metabolic scope. – Comparative Biochemistry and Physiology Part A: Physiology **105**: 609–615

Rao, M., McGowan, P.J.K. (2002): Wild-meat use, food security, livelihoods, and conservation. – Conservation Biology **16**: 580–583.

Richardson, J.A. (1998): Wildlife utilization and biodiversity conservation in Namibia: conflicting or complementary objectives? – Biodiversity and Conservation **7**: 549–559.

Richter, R. (2009): Atmospheric/topographic correction for satellite imagery. – Wessling: DLR report DLR-IB 565-01/09.

Rogers, L.K.R., French, J.R.J., Elgar, M.A. (1999): Suppression of plant growth on the mounds of the termite *Coptotermes lacteus* Froggatt (Isoptera, Rhinotermitidae). – Insectes Sociaux **46**: 366–371.

Roques, K.G., O'Connor, T.G., Watkinson, A.R. (2001): Dynamics of shrub encroachment in an African savanna: relative influences of fire, herbivory, rainfall and density dependence. – Journal of Applied Ecology **38**: 268–280.

Rothauge, A. (2002): New ecological perceptions of arid rangeland. – Agricola **11**: 49–56.

Saether, B.E. (1987): The influence of body-weight on the covariation between reproductive traits in European birds. – Oikos **48**: 79–88.

Sandel, B., Smith, A.B. (2009): Scale as a lurking factor: incorporating scale-dependence in experimental ecology. – Oikos **118**: 1284–1291.

Sankaran, M., Hanan, N.P., Scholes, R.J., Ratnam, J., Cade, B.S., Ardo, J., Augustine, D.J., Banyikwa, F., Bronn, A., Bucini, G., Caylor, K., Coughenour, M.B., Diouf, A., Feral, C., February, E., Frost, P., Gambiza, J., Gignoux, J., Hiernaux, P., Higgins, S., Hrabar, H., LeRoux, X., Ludwig, F., Metzger, K., Prins, H.H.T., Sea, W., Tews, J., Worden, J. (2005): Determinants of woody cover in African savannas. – Nature **438**: 846–849.

Scholes, R.J., Walker, B.H. (1993): An African savanna, synthesis of the Nylsvley study. – Cambridge: Cambridge University Press.

Scholtz, C.H., Holm, E. (1989): Insects of southern Africa. – Durban: Butterworths.

Schütze, S.J. (2009): Towards a sustainable use of the Devil's Claw: results from a simulation model. – Diplom thesis in Geoecology. Potsdam: University of Potsdam.

Schwager, M., Covas, R., Blaum, N., Jeltsch, F. (2008): Predicting climate change effects across scales – comparing a 'population model' and a 'space for time' approach. – Oikos **117**: 1417–1427.

Sefe, F., Ringrose, S., Matheson, W. (1996): Desertification in north-central Botswana: causes, processes, and impacts. – Journal of Soil and Water Conservation **51**: 241–248.

Seymour, C.L., Dean, W.R.J. (2009): The influence of changes in habitat structure on the species composition of bird assemblages in the southern Kalahari. – Austral Ecology. DOI: 10.1111/j.1442-9993.2009.02069.x

Seymour, C.L., Simmons, R.E. (2008): Can severely fragmented patches of riparian vegetation still be important for arid-land bird diversity? – Journal of Arid Environments **72**: 2275–2281.

Siegle, M. (2008): The termite genera Odontotermes and Macrotermes (Isoptera, Macrotermitinae): Feeding ecology in a traditional agriculture and soil restoration system (Zaï system) in Burkina Faso and plant growth on soils differently affected by termites. – Diplom thesis in Biology. Würzburg: University of Würzburg.

Simioni, G., Gignoux, J., Le Roux, X. (2003): Tree layer spatial structure can affect savanna production and water budget: results of a 3-D model. – Ecology **84**: 1879–1894.

Sirami, C., Seymour, C., Midgley, G., Barnard, P. (2009): The impact of shrub encroachment on savanna bird diversity from local to regional scale. – Diversity & Distributions **15**: 948–957.

Skarpe, C. (1990): Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana. – Journal of Applied Ecology **27**: 873–885

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (eds.) (2007): Climate Change 2007: the physical science basis. Contributions of working group 1 to the fourth assessment report of the Intergovernmental Panel on Climate Change. – Cambridge: Cambridge University Press.

Srivastava, D.S., Vellend, M. (2005): Biodiversity-ecosystem function research: is it relevant to conservation? – Annual Review of Ecology Evolution and Systematics **36**: 267–294.

Strohbach, M. (2002): Vegetation description and mapping along a strip transect in central Namibia with the aid of satellite imagery. – M.Sc. Thesis in Botany. Pretoria: University of Pretoria.

Strohbach, M., Cole, D. (2007): Population dynamics and sustainable harvesting of the medicinal plant *Harpagophytum procumbens* DC. (Devil's Claw) in Namibia. Results of the R+D Project 800 86 005. – BfNSkripten **203**. Bonn: BfN, Federal Agency for Nature Conservation.

Skutch, A.F. (1985): Clutch size, nesting success, and predation on nests of Neotropical birds, reviewed. – Ornithological Monographs **36**: 575–594.

Thiele, T., Jeltsch, F., Blaum, N. (2008): Importance of woody vegetation for foraging site selection in the Southern Pied Babbler (Turdoides bicolor) under two different land use regimes. – Journal of Arid Environments **72**: 471–482.

Thuiller, W., Araújo, M.B., Pearson, R.G., Whittaker, R.J., Brotons, L., Lavorel, S. (2004): Biodiversity conservation – uncertainty in predictions of extinction risk. – Nature **430**: 33

Tietjen, B., Zehe, E., Jeltsch, F. (2009a): Simulating plant water availability in dry lands under climate change: a generic model of two soil layers. – Water Resources Research **45**: W01418. DOI: 10.1029/2007WR006589.

Tietjen, B., Jeltsch, F., Zehe, E., Classen, N., Groengroeft, A., Schiffers, K., Oldeland, J. (2009b): Effects of climate change on the coupled dynamics of water and vegetation in drylands. – Ecohydrology. DOI: 10.1002/eco.70.

Toit, J.T. du, Cumming, D.H.M. (1999): Functional significance of ungulate diversity in African savannas and the ecological implications of the spread of pastoralism. – Biodiversity & Conservation **8**: 1643–1661.

Valentin, C., d'Herbès, J.M., Poesen, J. (1999): Soil and water components of banded vegetation patterns. – Catena **37**: 1–24.

Vogel, M. (2006): Erfassung von Vegetationsveränderungen in Namibia mit Hilfe von Fernerkundungs-Change-Detection-Verfahren und unter Berücksichtigung rezenter Niederschlagsereignisse. – PhD in Natural Sciences. Würzburg: University of Würzburg.

Vogel, M., Strohbach, M. (2009): Monitoring of savanna degradation in Namibia using Landsat TM/ETM+ Data. – International Geosciences and Remote Sensing (IGARSS) Cape Town, South Africa, 13-17 July, 2009. http://hdl.handle.net/10204/3574.

Wasiolka, B., Jeltsch, F., Henschel, J., Blaum, N. (2010): Space use of the Spotted Sand Lizard (*Pedioplanis l. lineoocellata*) under different degradation states. – African Journal of Ecology **48**: 96–104.

Watson, J.P. (1976): The composition of mounds of the termite *Macrotermes falciger* (Gerstäcker) on soil derived from granite in three rainfall zones of Rhodesia. – Journal of Soil Science **27**: 495–503.

Weber, G.E., Jeltsch, F. (2000): Long-term impacts of livestock herbivory on herbaceous and woody vegetation in semiarid savannas. – Basic and Applied Ecology **1**: 13–23.

Weber, G., Moloney, K., Jeltsch, F. (2000): Simulated long-term vegetation response to alternative stocking strategies in savanna rangelands. – Plant Ecology **150**: 77–96.

Wessels, K.J., Prince, S.D., Frost, P.E., Zyl, D. van (2004): Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. – Remote Sensing of Environment **91**: 47–67.

Wessels, K.J., Prince, S.D., Malherbe, J., Small, J., Frost, P.E., Zyl, D. van (2007): Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. – Journal of Arid Environments **68**: 271–297.

Westoby, M., Walker, B., Noy-Meir, I. (1989): Opportunistic management for rangelands not at equilibrium. – Journal of Range Management **42**: 266–274.

Whitford, W.G., Parker, L.W. (1989): Contributions of soil fauna to decomposition and mineralization processes in semiarid and arid ecosystems. – Arid Soil Research and Rehabilitation **3**: 199–215.

Wichmann, M.C., Jeltsch, F., Dean, W.R.J., Moloney, K.A., Wissel, C. (2003): Implication of climate change for the persistence of raptors in arid savanna. – Oikos **102**: 186–202.

Worldbank (2008): Environment matters at the Worldbank. Annual report 2008. – http://go.worldbank.org/MGIBT1PLO0. [acc. 11.06.2010]

Wyk, J.A.P. van (1988): Biomassa as basis vir bestokking. – Agricola **6**: 12–16.

Zeidler, J., Hanrahan, S., Scholes, M. (2002): Landuse intensity affects range condition in arid to semi-arid Namibia. – Journal of Arid Environments **52**: 389–403.

Zimmermann, I. (2009): Causes and consequences of fenceline contrasts in Namibian rangeland. – PhD thesis. Bloemfontein: University of the Free State.

Zimmermann, I., Smit, G.N. (2008): Case study of adaptive rangeland management by an innovative Kalahari farmer. – Agricola **18**: 7–16

Zimmermann, I., Joubert, D.F., Smit, G.N. (2008): A problem tree to diagnose problem bush. – Agricola **18**: 27–32.

Farm settlement in the Nama Karoo. Photo: N. Dreber.

Part IV

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An ecological-economic analysis of the pastoral systems of the Nama Karoo in southern Namibia

Stephanie Eileen Domptail*, Niels Dreber, Thomas Falk, Tarig Gibreel, Michael Kirk, Cornelia Limpricht, Christiane Naumann, Sebastian Prediger, Björn Vollan & Dirk Wesuls

Summary: The chapter presents an ecological-economic analysis of pastoral systems in the form of an interdisciplinary study on livelihoods, landuse practices, and related environmental impacts. The study focuses on three different pastoral systems of the Namibian Nama Karoo that differ in terms of climate, and cultural and socio-economic backgrounds: (i) the northern and more humid farmlands of the Rehoboth area about 80 km south of the capital Windhoek, characterised by small farm sizes and private and multiple-ownership land tenure; (ii) the large private meat- and pelt-producing ranches in the arid southern Namibia in the vicinity of the city of Keetmanshoop; and (iii) the semi-commercial goat production system in the communal areas of the neighbouring Namaland. Research results from nine case studies constitute the basis for the analysis. After a brief description of the landuse and management history of each pastoral system, three subchapters summarise the investigation of important drivers of the landuse strategies and of the dynamics of each system in general. Related impacts on biodiversity are also reported, with a special focus on land degradation.

The multi-faceted diversity, which characterises the Namibian Nama Karoo, was one of the most striking results. A major aspect is the diversity of tenure systems: the analysis reveals that no tenure system is a panacea and solutions for sustainable management should be sought within each social-ecological system as they consist of tightly coupled dynamics between the natural rangelands and the local social and economic systems. However, some general insights into the functioning of these systems were gained and are presented in an overall summary at the end of the chapter, which points out some implications for research with regard to the different pastoral systems in the Nama Karoo.

3.1 Introduction

[N. Dreber]

The Nama Karoo is the second largest biome and one of the driest of the southern African subcontinent. It covers a third of South Africa and most of southern Namibia and extends northwards into the more humid Thornbush Savanna. The climate is semi-arid to arid with a high spatio-temporal rainfall variability. The dominant vegetation type is dwarf shrub savanna (Palmer & Hoffman 1997). Due to the harsh climatic constraints and the subsequent limited and variable annual biomass production, farming with small stock, i.e. sheep and goats, is the most widespread pastoral activity on freehold tenure land and in communal areas (Mendelsohn 2006). However, with an increase in rainfall towards the semi-arid savannas of central Namibia, farming with cattle becomes profitable. Land degradation is commonly observed in the rangelands of the Nama Karoo, and is mainly driven by the variable climatic conditions and unsustainable management practices (Klintenberg & Seely 2004), which may occur both on commercial ranches and on communal lands (Byers 1997). An ecological-economic analysis of the pastoral systems consisting of an interdisciplinary study on livelihoods, landuse practices, and related environmental impacts was conducted within the BIOTA Southern Africa project. For this purpose, two focus regions differing in terms of climate and cultural and socio-economic background were chosen within the Namibian Nama Karoo.

One focus was on the farmlands of the Rehoboth area about 80 km south of the capital Windhoek. This area is situated in the transition zone between the Nama Karoo and the central Namibia savannas (Giess 1971), and thus in a more humid part of the Nama Karoo. Characteristic for the region are small average farm sizes often with multiple ownership and a relatively low proportion of full-time farmers. The second study area was located in the drier area of Keetmanshoop about 400 km south of Rehoboth. Here, two contrasting pastoral systems were investigated. On the one hand commercial ranching systems, i.e. privately owned large farms specialising in large scale production of meat and pelts, and on the other hand a semi-commercial goat production system in the communal areas of the Namaland.

In the following analysis, the social-ecological systems within the rangelands of the Rehoboth and Keetmanshoop areas are first introduced by describing the landuse and management history of the region. Together with the region's natural resource heterogeneity these components form an important determinant of farming opportunities and strategies. Second, drivers of landuse and of the social-ecological systems are explored. Related impacts on biodiversity highlighting the problem of land degradation are reported upon in a third section. We conclude with an overall summary of the main issues and point out the implications of the research for distinct pastoral systems in the Nama Karoo.

3.2 Rehoboth area: dynamics of small-scale commercial pastoral systems

The region and the town of Rehoboth

[C. Limpricht]

The core area of Rehoboth is inhabited by the Rehoboth Basters and is comprised of parts of the **Hardap and the Khomas Region.** It can be divided geologically into three adjacent zones: the Khomas Hochland Plateau, the Rehoboth Plateau, and the Kalahari Sandveld. In addition, three vegetation zones are to be found: the Highland savanna, the dwarf shrub savanna and the mixed tree and shrub savanna of the southern Kalahari (Giess 1971). The climate of this area is semi-arid with a long-term mean annual rainfall of about 250 mm. Apart from a few exceptions there is no year-round open water in the region. The land has been, and still is only used for animal husbandry, the prime herd animals being cattle, sheep, and goats.

The town of Rehoboth is situated close to the boundary of the Hardap and the Khomas Region. This is a recently drawn boundary dissecting the area of farms, the former Rehoboth Gebiet, which had been reserved exclusively for Baster owners until the Independence of Namibia in 1990. **Rehoboth** is the seventh largest town of Namibia, having approximately 30,000 inhabitants (21,300 according to the national census of 2001). Today Rehoboth is a regional centre with members of nearly all Namibian groups living in the town. The Oanob Dam, a smaller counterpart of the Hardap Dam, is situated on the outskirts of the town of Rehoboth offering an important resource for tourism.

Photo 1: Landscape to the north west of the town Rehoboth. Photo: Dirk Wesuls.

The Rehoboth Baster Community

[C. Limpricht]

The Rehoboth Basters, representing little more than 2% of the Namibian population (2 million in 2007), identify themselves as distinct from other groups of mixed descent on account of their right to **land ownership** as well as their peculiar history which reaches back into the middle of the nineteenth century. In 1868 they embarked on an exodus from the oppressive colonial rule at the Cape in search of land on which they could make a living by farming with large and small stock. They were pious Christians led by their Kaptein and a German missionary.

After settling peacefully in Rehoboth in 1870 the Rehoboth Basters began to distribute farms to members of the community in about 1895 and thus started a **transition from communal to private ownership of land** (Lang 1999). Population increase, inheritance pattern and political constraints during the better part of the 20th century led to the **splitting up of farms** (Fig. 1) into units which were no longer economically viable but which were of great social significance. Survey data gained in 2000 show that the process of subdividing farms must have at least slowed down considerably in recent years (Lang 2005). It can be inferred from the survey data (Lang 2005) that the **continuation of the fragmentation trend** is the result of a change in the value orientation of the farm owners. While Basters are found in jobs all over the country, the farm or home in Rehoboth remains the ultimate refuge or retreat. A rural ambience and the freedom which comes with owning a farm remain an ideal.

The Rehoboth farm system and its typology today

[C. Limpricht]

On the farm map of Namibia (Fig. 1), the Rehoboth Gebiet is easily identified due to the fact that the farms are heavily fragmented and subdivided. What caused this density? By the end of the 19th century, the Basters had enough space to grant every Baster applicant a farm of 7,000 ha. Twenty-five years later, with a population growth rate of about 3%, the limits were reached and all farmland had been distributed (Lang 1998). Combined with rules of inheritance giving each child an equal share of the farm, the farms became heavily subdivided within a few generations. During the Apartheid years even wealthier Basters were not allowed to buy land outside the Gebiet and thus political constraints added to land scarcity. These driving forces, population growth rate, inheritance rules and political constraints brought about two types

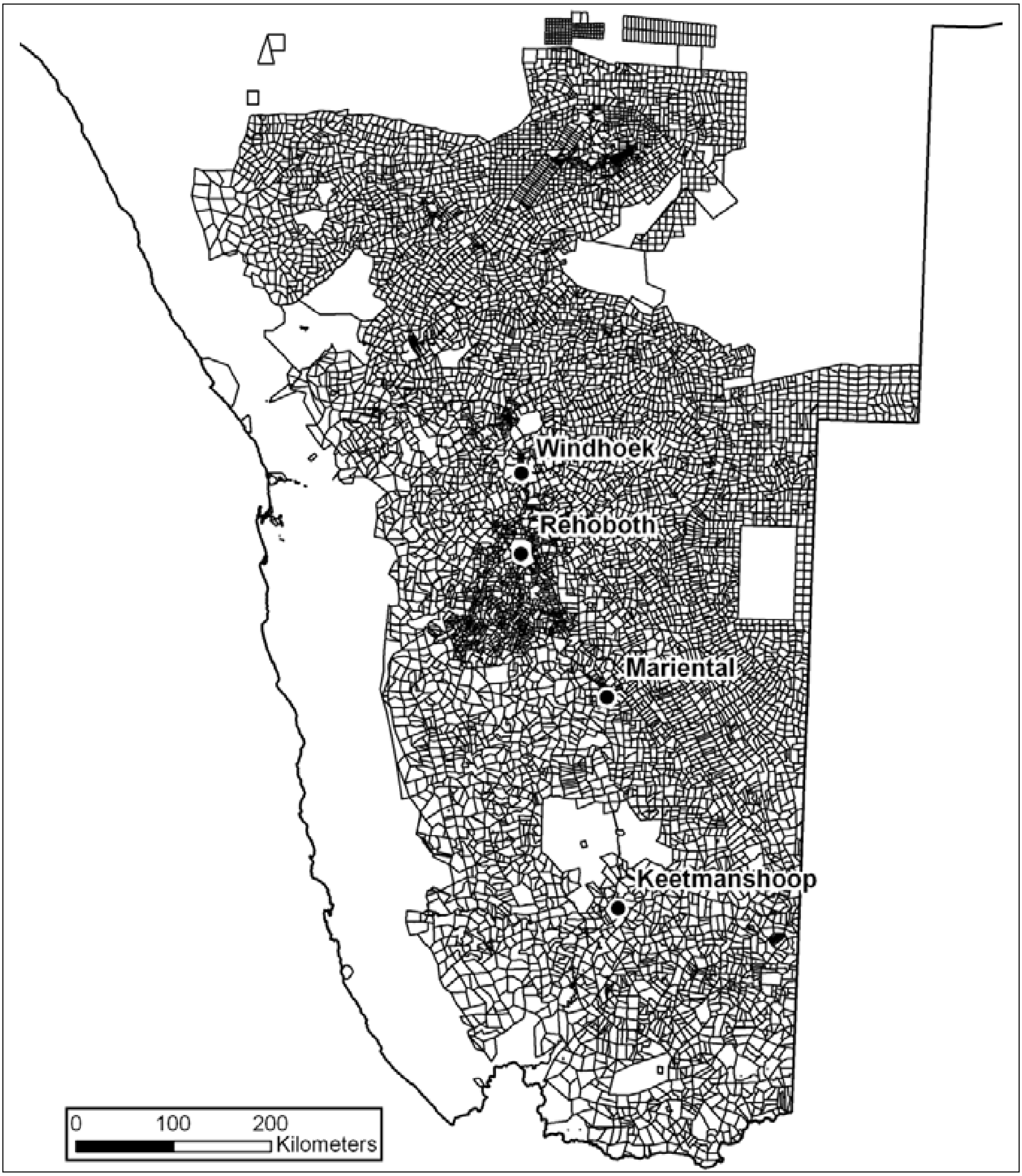


Fig. 1: Farm map of Namibia showing a concentration of comparatively small farms around Rehoboth (former Rehoboth Gebiet).

of farms, which in turn has led to a third type (Lang et al. 2004, Lang 2005):

1. Estate farms under multiple ownership
2. Small farms under single ownership
3. A few fairly large consolidated farms under single ownership

Type 1. So-called estate farms under multiple ownership are inherited farms, where all owners are related by blood or marriage. If several owners share a farm, their individually-inherited hectares are valuated and registered even today as undivided shares, which seems to be a peculiarity of land holdings in Rehoboth. Consequently the individual has no right to a specific piece of land. For example, ten owners with undivided shares of an 800-hectare farm would not be able to identify their own 80 hectares, and there are farms with more than 50 owners. This type of arrangement contains a potential for conflicts as well as negative effects on pastures.

Type 2. Small farms—smaller than 4,000 ha under single ownership, managed usually on a part-time basis: These farms usually had been fragmented in the past by inheritance but one single owner has managed to buy out co-owners and register the farm. These farms face ecological and economical problems.

Type 3. The rather large consolidated farms, run by a single owner, sometimes full-time, with a size of more than 4,000 ha have been developed only rarely. These farms mostly started as estate farms but one heir managed to buy out the other relatives and even succeeded in purchasing or exchanging neighbouring parcels of land in order to consolidate all the parcels into a bigger registered farm.

These three types of farms have not only different impacts on biodiversity but also on the quality and quantity of economic output.

How are these three types of farms being spread over the Rehoboth area and how representative is this grouping? Data gained from our survey (Fig. 2) conducted in 2000 provided a clear indication of these three main types of farms (Lang 2005). The survey showed that farm size and ownership structure—single versus multiple ownership—are independent factors. Thus one finds farms larger than 4,000 ha with multiple owners as well as smaller ones. In our survey sample, single ownership dominates the farm system while multiple ownership is found on a quarter of farms.

In the Rehoboth area 4,000 ha can be seen as a threshold for starting as a full time farmer. This threshold depends, of course, on individual aspirations with regard to the standard of living. There are full-time farmers on farms of 2,500 ha and the biggest farm of 11,000 ha was run part-time by a shop owner. Although fragmentation has been largely halted, it is still part of the system since roughly 80% of the Rehoboth Gebiet comprises farms smaller than 4,000 ha (Lang 2005: 233). Only 20% of the Gebiet consists of farms of more than 4,000 ha. But the data also indicate that the process of fragmentation has discontinued and a reverse process has started (Fig. 3).

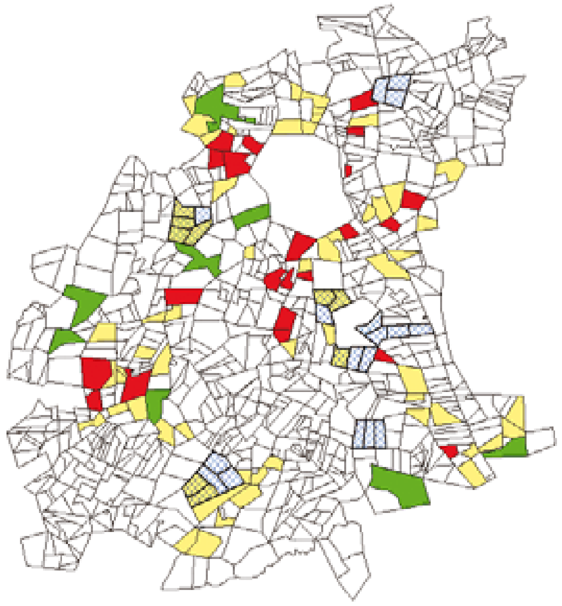


Fig. 2: The former Rehoboth Gebiet. Survey of farms and Odendaal-farms (Limpricht & Lang 2008). Red: estate farm with many owners. Yellow: Farm, run part-time by a single owner (< 4,000 ha). Green: large (consolidated) farm, run full-time by a single owner (> 4,000 ha). Blue cross-hatching: Odendaal farms (mean size 2,400 ha).

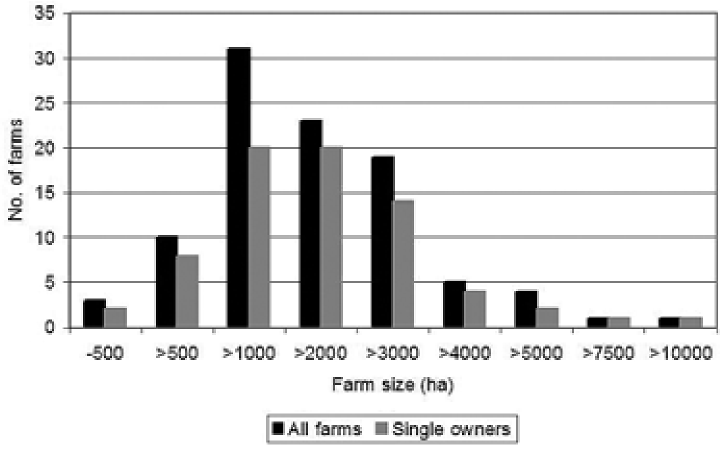


Fig. 3: Farm size distribution of all farms (including multiple owner farms) and single owner farms in 1999/2000 (Lang 2005).

The Rehoboth Odendaal-farms—a good example in land re-distribution?

[C. Limpricht]

During the late 1960s, the South African government purchased six white owned farms—the so-called **white islands** of the Baster Gebiet—comprising more than seventy thousand hectares. They were subdivided into twenty-six units, which were leased and later sold to Baster farmers. The idea to incorporate these farms into the Baster homeland came from the South African official F.H. Odendaal in 1964. Within the framework of South African Apartheid ideology and its racist goal of separate development, the Baster homeland was consolidated with the removal of white farmers from the region (Britz et al. 1999, Limpricht & Lang 2008).

The Realisation of the Odendaal Plan: The first step was the subdivision

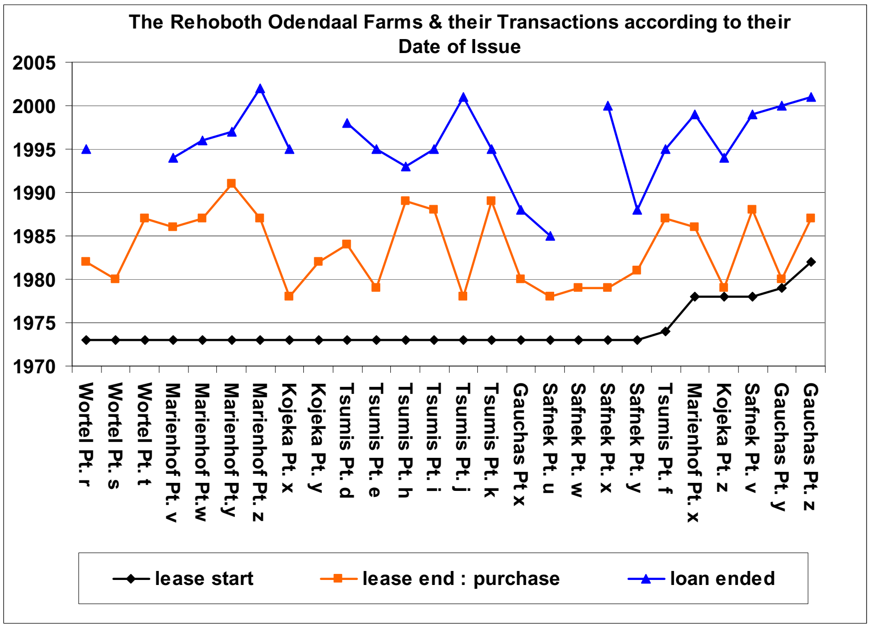


Fig. 4: Rehoboth Odendaal Farms: six farms were subdivided into twenty-six units.

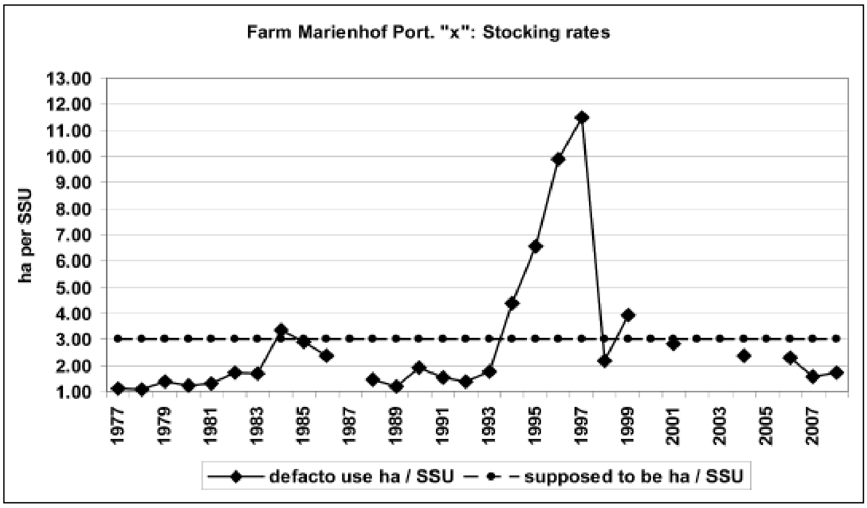


Fig. 5: The graph gives a rough idea about sticking to prescribed stocking rates. We used only the numbers of adult animals as the numbers of lambs and calves were incomplete.

of these rather large and mainly well-developed farms into smaller surveyed parcels, which ranged from little more than 2,000 ha to nearly 2,800 ha. The distribution of fences—camps and borders—had to be reorganised. Each unit had to get access to a water point. On paper, a detailed planned infrastructure with camps and water points was made available for each unit by the end of the 1970s. The single units were advertised. Within nine years the South African administration managed to purchase and to subdivide the **white islands**. Nearly all farms were allotted in 1973 with a five-year lease and an option-to-buy-contract to Baster farmers, after they had successfully completed a one year period of a lease-on-probation (Fig. 4). Five farms were given up by the first lessee for different reasons and the farms were distributed again: 3 in 1978, 1 in 1979, 1 in 1982. What becomes clear is that during the process of allotment the Basters were not lumped together but treated with individual solutions; otherwise we might have found a correlation between the different transactions of leasehold, purchase and pay off (Fig. 4).

Farm Marienhof: We focus here on some preliminary results of aspects like farm planning, subsidies and survival strategies of the Odendaal-owners, using mainly the case of the farm Marienhof. Originally 11,099 ha, Marienhof was divided up into five pieces (portions) in 1971. Today three of the original Odendaal-owners are more or less active, but rather old. One unit was sold to a third party, while one unit was passed as gift to the son.

Regarding farm planning, the Odendaal rules are stricter on paper than in reality: Some owners followed the envisaged detailed farm-plans made by the local agricultural department, which made provision for the location of camps, boreholes, water distribution, and rotational pasture management, while others did so only partly or did next to nothing. There is at the moment no case to be found where farm planning was enforced, but out of the archival material it has become clear that whenever subsidies were claimed, e.g. for farm investments like camp fences, owners had to stick to the plans and also to certain stocking rates. Nevertheless, overstocking the farm developed into a survival strategy due to the size of the farms.

Only one of the Marienhof farms still has the full records of stock numbers for the last 30 years. During this period the owner met the prescribed stocking rate of 3 ha per small stock unit (SSU) only six times, although this stocking rate was not high (Fig. 5). The farm does show signs of degradation in an increased number of annual grasses, and certain camps are dominated by the invasive *Acacia mellifera* (Swarthaak). But interestingly, despite this long period of heavy overstocking and corresponding degradation, the farm is still able to support a viable livestock production.

Most of the farmers of the southern Odendaal-farms indicated that they had to rent additional farms in order to survive. All interviewed farmers confirmed that the Odendaal allotment was the only chance for landless Basters, although it became clear quite early that the farms were rather small. In these days they could make a modest living, raise between three to ten children, and send them to school and sometimes university.

Conclusion: The whole process of re-distribution was inspired by an objectionable political system (Apartheid), but nevertheless it can be seen as an intervention experiment by a state to change property rights. This historical case of the re-distribution of private land in the Rehoboth Gebiet sheds light on aspects of the economical and ecological feasibility of such a process. The reconstruction of farm histories and landuse patterns indicates that the Odendaal farms can serve as a politically necessary, but not always ecologically positive, exemplary basis for redistributing land today (Hunter 2004, Odendaal 2006). The Odendaal farmers who were especially successful economically were those who accepted guidance and assistance from the local agricultural extension service if they could manage the risk of additional loans and if they joined the agricultural unions. The support of sometimes large subsidies helped a great deal.

Ethnobotanical knowledge

[C. Naumann]

Landusers perceive the flora of the area from a pastoral point of view and evaluate plants according to their relevance for their herds. Their knowledge focuses on plants which are well utilised by grazing or browsing animals, or which are known to be toxic for livestock. The use of plants for veterinary purposes can be observed in the region; in particular the application of *Aloe* spp. (Alwyn) for tick control is widespread among local landusers. However, the prevention and treatment of human ailments with medical plants is only reported by a few farmers (Naumann 2009).

Nutrition value, palatability, and biomass production are important local criteria for plant valuation. Species which are annual or occur in predominantly disturbed habitats are not necessarily seen as inferior, as long as they are well utilised by livestock and improve the animals' physical condition. Furthermore, the time of germination is an important local valuation criterion. Species germinating and establishing quickly after rainfall events, such as the annual grass *Enneapogon desvauxii* (Agdaegras), are admired, since they offer the first green grazing after a dry season.

Consensus analysis was used to investigate the distribution of cultural botanical knowledge within the farmer community in Rehoboth (Naumann 2009). Results showed that knowledge is unequally distributed among the farmers. Landusers that have a good knowledge of the local flora are generally senior full time farmers, who have many years of experience and are actively involved in farmer unions. Surprisingly, a comparison of botanical data concerning the perennial grass biomass on landusers' farms with results of consensus analyses suggests that local botanical experts are not necessarily the better pasture managers.

Local perceptions of degradation

[C. Naumann]

Degradation of vegetation and soils can be observed in many places in the former Rehoboth Gebiet. Numerous farms are covered predominantly with annual grass species and show signs of soil erosion. The degradation of pastures is also perceived by local farmers, in particular the decrease of perennial grass species, sheet erosion processes and the die off of *Acacia erioloba* (Kameeldoring) individuals. Landusers have varying explanations for the causes of this trend. Some farmers assume that change of vegetation is a result of decreasing precipitation. However, available rain data dating back to the 1980s do not indicate at least a short-term decline in annual rainfall. Besides precipitation, failure in farm management is seen by many local farmers as an important reason for degradation processes in the area. Especially high stocking densities are perceived as a problem for the local environment.

Change of vegetation, e.g. the decrease of perennial grasses and increase of annual species, is not regarded as alarming as long as pastures remain highly productive (see above). If land is strongly degraded and offers insufficient animal nutrition the long-term rest of rangeland is seen as the best means to increase pasture condition (Naumann 2009).

Environmental heterogeneity and productivity of the Rehoboth rangelands

[D. Wesuls]

The common features regarding the cultural and historical background of the Rehoboth area are contrasted by a high environmental heterogeneity and by a steep rainfall gradient. Coming from the foothills of the Khomas Highland in the north with an average annual rainfall of 350 mm, the rainfall is nearly halved within the next 100 km down southwards to 200 mm or even less in the southern parts near Kalkrand. As already mentioned in the introductory part, three geologically distinct units and three vegetation zones are to be found in the Rehoboth area.

In a botanical survey of ten different farms in the area conducted in the good rainy season of 2006 the plant species composition and cover were recorded on 10 m x 10 m samples on typical parts of these farms. Additionally a sample of the grass biomass was taken on a 1 m x 1 m sample within each of the larger vegetation sampling plots. The vegetation samples were classified by means of cluster analysis and detrended correspondence analysis (DCA).

Fig. 6 shows the three different vegetation classes that could be identified. The classes are mainly related to the different soil types which also reflect the different geological units. Class 1 was found on shallow calcareous (Calcisols) and rocky soils (Leptosols). The typical vegetation found here was a mix of grasses and dwarf shrubs. Class 2 could be related to sandy soils of medium depth. This class represented an open shrub savanna with taller shrubs compared to class 1. The vegetation of classes 1 and 2 are typical for large parts of the Nama Karoo. Class 2 comprised most of the samples and it is quite characteristic for the Rehoboth area. Class 3 was found on deep sandy soils (Arenosols). These soils are advantageous in terms of water infiltration and water storage allowing for taller trees and shrubs to grow. Consequently, the vegetation found here was characterised by a higher density of large trees and shrubs within a continuous grass layer. This vegetation represents a part of the southern Kalahari found in Namibia.

Grasses are the basis for farming in the savannas of the Rehoboth area as they contribute most to the annual biomass production and they represent the main fodder for livestock. Different species

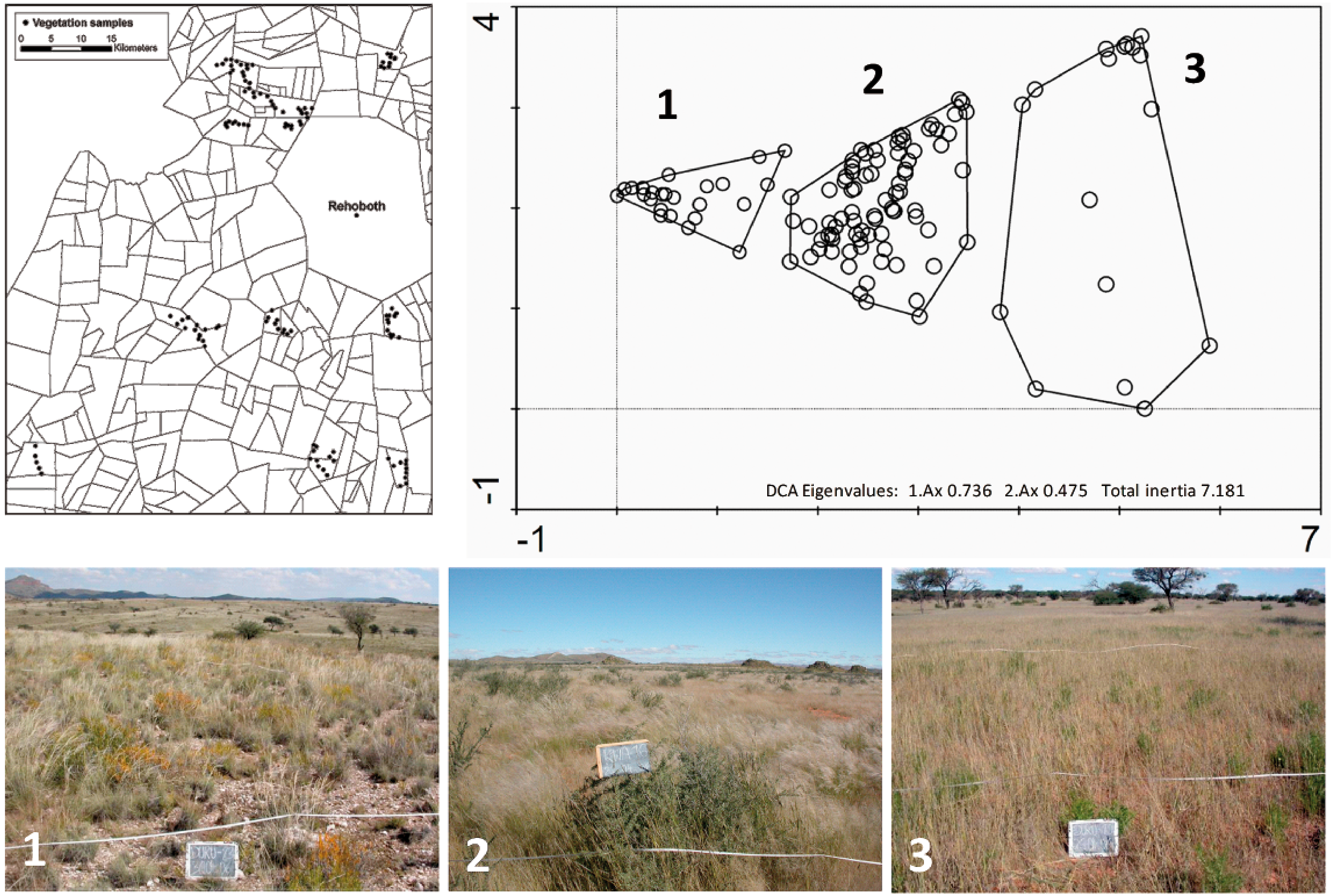


Fig. 6: Farm sampling conducted in 2006 in the Rehoboth area. Top left: Map of the ten sampled farms. Top right: DCA ordination of vegetation samples. Three distinct classes (top right and photographs below) which are mainly related to different soil properties could be identified. Class 1: Dwarf shrub savanna on rocky and calcareous soil. Class 2: Shrub savanna on sandy soil. Class 3: Tree and shrub savanna on deep sandy soil.

differ in their nutritive value and their ecological significance. Annual grasses are seen as valuable fodder since their protein content is often very high (see Wesuls et al. 2009). Nevertheless, vegetation with a high proportion of annual grasses is also a signal of ecologically impoverished pastures in an unfavourable state or an early state of plant succession. Compared to perennial grasses they are less reliable in terms of biomass production in poor rainy seasons and because of their shallow rooting depth they do not prevent soil erosion. The differences between the ten sampled farms in terms of biomass of annual grasses (Fig. 7a) mainly reflected patterns of rainfall. The highest amount of annual grasses was found on the smallest farm, belonging to vegetation class 3. This high biomass was mainly due to an extraordinary high rainfall (> 500 mm) on that farm in the sampling season. The grass biomass of this farm was mainly determined by *Schmidtia kalahariensis*, a very productive annual grass, typically growing on deep sandy soils. There was no significant correlation between the biomass of annual grasses and farm size (shown as grey boxes in Fig. 7).

Other farm management parameters like the current and past stocking rate and the number of camps per farm showed no significant correlation with the biomass of annual grasses. The same applied to the biomass of perennial grasses. Nevertheless, perennial grasses tended to be more abundant on larger farms although this correlation was very close to the significance threshold (Pearson $r = 0.62$, $p = 0.055$). On average, the highest amount of perennial grass was found on the two largest farms (Fig. 7b). Despite the fact, that the highest values for the overall biomass were again found on the two largest farms (Fig. 7c) there was no general significant trend of the total grass biomass (i.e. annuals and perennials) regarding farm sizes, stocking rates or number of camps.

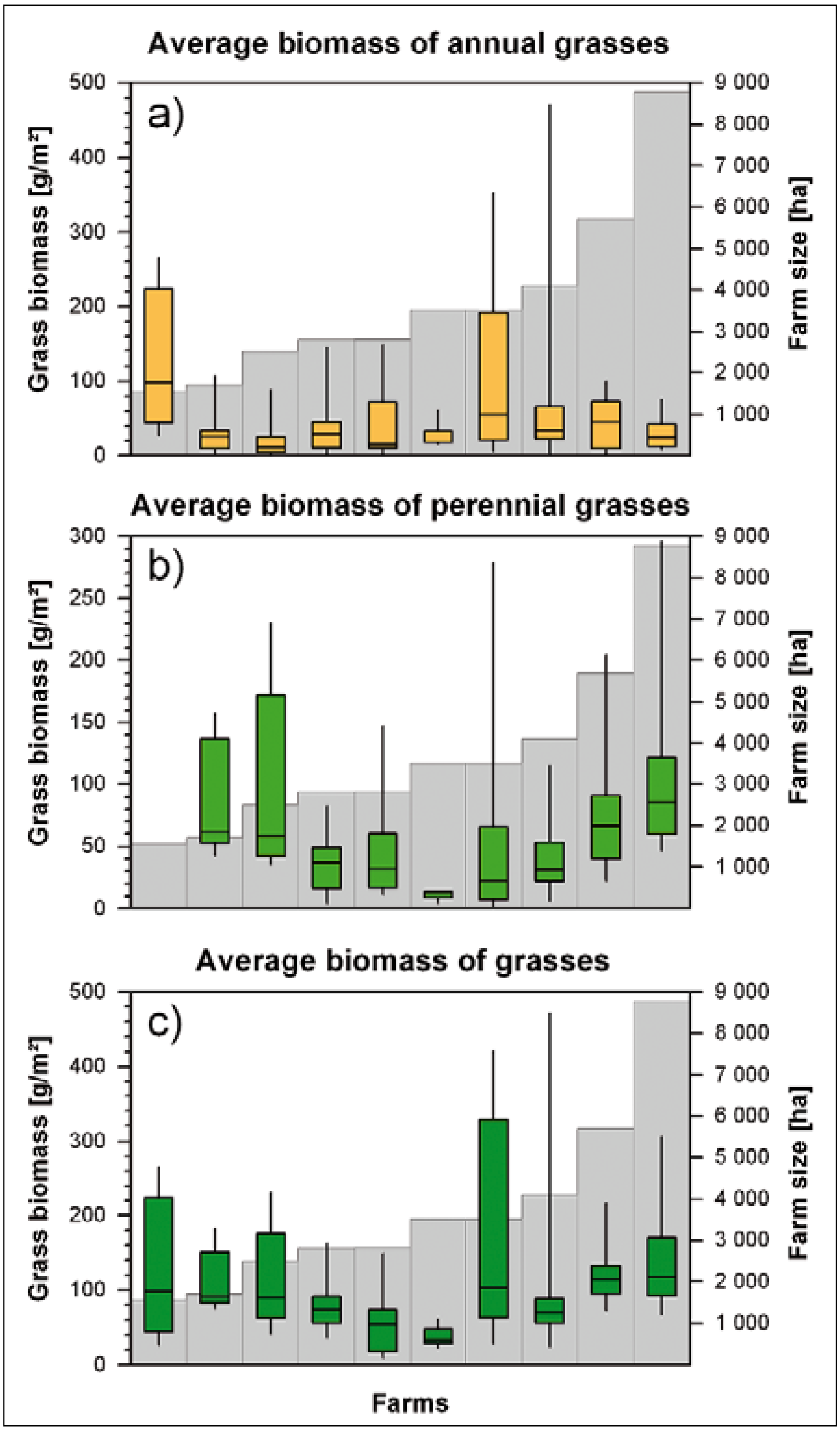


Fig. 7: Average biomass of annual (a), perennial (b) and the sum of all grasses (c) on ten farms in the Rehoboth area. The horizontal line in the boxes is the median value ($N = 5–22$). The boxes represent the interquartile range (25–75%) and the whiskers the total range. Light grey boxes in the background show the farm sizes.

Conclusions: It becomes apparent, that a comparison of farms which is feasible in terms of socioeconomic factors could be difficult when the factors to be compared are based on environmental and ecological criteria. The environmental heterogeneity described for the Rehoboth area also showed up in the sampling of vegetation and grass biomass on ten different farms. The productivity of the Rehoboth rangelands is driven by this heterogeneity and by local patterns of rainfall. Nevertheless, the tendency of higher perennial grass biomass on larger farms shows that there are important background variables that affect whether management is sustainable or not. Some of these additional factors have been already mentioned in the preceding sections, e.g. ownership structure, ethnobotanical knowledge or perceptional concerns (see also Wesuls &

Lang 2010). For future research it would be desirable if environmental heterogeneity is kept at a minimum when comparing the effects of farm management on productivity. Furthermore a detailed analysis and integration of all factors that may influence farm management will be necessary in such comparisons.

Recommendations—targeting the regions—the former Rehoboth Gebiet

[C. Limpricht]

The size of the farms and the ownership structure influences the ecological and economic viability of farming since multiple ownership is found on a quarter of farms in the Rehoboth area (Limpricht & Lang 2008). Roughly 40% of the former Rehoboth Gebiet is used by farms smaller than 2,000 ha (Lang 2005).

Small farms and multiple-owner farms often suffer from incoherent and inconsistent pasture and stock management. Before Independence in 1990, **farm planning** was one of the major tasks of the Rehoboth extension service, which formed part of the agricultural department. Today it happens very rarely. Farms of multiple owners and small farms receive hardly any attention. A change of this attitude would be an improvement. Since farm consolidation is a time-consuming effort and not always successful, farmers and stakeholders could consider developing mechanisms for **farming jointly**, either within family structures or by including neighbouring small farms. This could stimulate thinking about new cooperative structures, smaller types of conservancies or forms of informal consolidation.

Due to individualistic attitudes and almost isolated work routines on their farms, the Rehoboth farmer community nowadays faces the problem of not knowing weather neighbours or farmers in the vicinity are going to sell or lease a piece of land. A **board or commission**, established under the auspices of the Rehoboth Extension Office of the Ministry of Agriculture, Water and Forestry and the Agricultural Unions of Rehoboth, could serve as an information collecting point, through which everyone who wants to sell or to purchase a farm, a portion, or shares of a farm has to operate. Neighbouring farmers and established farmers of the area should have first choice to buy such properties in order to get a chance to enlarge their farming activities so that they can become more ecologically and economically viable.

3.3 Keetmanshoop region: socio-economic analysis of large commercial ranching systems of south-central Namibia

Introduction to commercial farming systems

[S. Domptail & N. Dreber]

Research on commercial farming systems of the arid Nama Karoo and their impact on rangeland ecological condition started in 2004 in a study area of about 750,000 ha in the surroundings of the main town of the Karas region, Keetmanshoop. The Gellap Ost research station, hosting a BIOTA Observatory Gellap Ost, is located within this area. In total from 2004 to 2007, about 40 commercial farmers were interviewed.

Ecological context. Most of the study area consists of extended plains covered by grasses and dwarf shrubs, which are dissected by washes ending in larger river beds. Locally, prominent dolerite hills, shale ‘inselbergs’ and plateaus occur, which are sparsely vegetated. The climate is arid, characterised by erratic and low summer rains from December to April (150 mm on average). Rainfall follows an incomplete gamma distribution so that there are more below average than above average rainfall years, and frequent droughts. In this harsh environment perennial grasses, dwarf shrubs, and higher shrubs compete for scarce water resources. Most shrubs and grasses are of value as fodder with some species being more palatable than others are. Trees, mostly *Acacia* spp., are found in moist habitats such as river beds and along the beds of underground rivers. Characteristic species in the region are *Stipagrostis uniplumis* (Blinkhaarboesmangras), *S. ciliata* (Langbeenboesmangras), *S. obtusa* (Kortbeenboesmangrass) for the grasses, *Monechma genistifolium* (Perdebos) and *Petalidium linifolium* (Lusernbos) for the dwarf shrubs, *Rhigozum trichotomum* (Driedoring), *Boscia foetida* (Stinkbos), *Catophractes alexandri* (Gabbabos) and *Tetragonia schenckii* (Kooibos) for the taller shrubs, and *A. erioloba* (Kameeldoring), *A. mellifera* (Swarthaak), *A. nebrownii* (Soetdoring) for the trees. Degradation implies a change in the vegetation composition of the rangeland and consists primarily of the replacement of perennial grasses by annual ones and an increase of bare ground. Degraded areas can be also subject to bush encroachment by less desirable shrubs such as *Zygophyllum tenue* (Skilpadbos) on lime soils or by *Rhigozum trichotomum*. Biomass growth varies inter-annually quite strongly in the Karas region—with a coefficient of variation from 20% to 40%—which constitutes the major challenge for pastoral activities. Yet, at the location of the study site, biomass is even more variable with a coefficient of variation above 90% (MAWF 2004).

Farmers and farming systems. Commercial ranches occupy a majority of the rangeland suitable for pastoralism in this region. The commercial farms are family enterprises but employ a small number of workers. The majority of owners and managers belong to the Afrikaners ethnic group while the workers belong to the Nama, Ovambo, San or Kavango people. Most of the farmers belonging to the Afrikaans ethnic group and their households consist of the nuclear families, with seldom more than three children. Living standards (large house, tertiary education of the children, and ownership of a car) are rather high compared to the Namibian average. Until now, this was possible thanks to low costs of inputs and large farm sizes. The average farm size in the sample is 10,000 ha (S. Domptail, unpublished data) with average net margins oscillating around N$35 (about €3) per ha (Schuh et al. 2006). Workers enjoy many benefits in kind, including housing, but are often paid the minimum legal salaries. There is now pressure to increase their salary and thus the labour costs on farms (Karamata 2006). Commercial farmers mostly belong to farming families and have grown up on communal or commercial farms. This trend is changing with a high turnover of land ownership and management, resulting from the land redistribution effort conducted in the context of the land reform (Kahuika 2006). At the moment, many people enter the commercial farming profession without specialised knowledge about farming systems nor market oriented production.

Economic background. The commercial farms are specialised in the production of meat and sheep skins for sale, rather than self-consumption. The breeding of small stock, characterised by a short life cycle and fast herd dynamics, is the most suitable pastoral activity considering the climatic constraints. Skin production with Karakul sheep (i.e. fur from newborn sheep, also known as Astrakhan or Swakara) was the main pastoral activity in the region until the 1980's. Skins, referred to as 'Black Gold', were exported centrally by the national cooperative AGRA to Copenhagen. Yet, the market is characterised by a high volatility in prices. Following the price crash in 1979 (AGRA 2005, unpublished data), the region largely converted to meat production activities based on the breeding of Dorper sheep (a cross-breed of the English Dorset meat sheep with the indigenous Persian sheep). Other indigenous sheep breeds may occasionally be found on farms as well. Prices for meat products are less volatile, while still variable. They are affected by the Small Stock Marketing Scheme implemented in 2006 with the aim of adding value to the livestock industry in Namibia by strongly limiting the export of live sheep to neighbouring South Africa (Schutz 2009). National abattoirs, such as that of Keetmanshoop, create incentives through their pricing policy for the production of lean meat with Dorper sheep rather than of fattier meat from indigenous sheep. Finally, goat farming belongs, especially among the Nama ethnic group, to the traditional small stock breeds and is conducted largely as a side production on most farms. At the moment, goats are still exported live, mostly to the large market, which exist in South Africa. Table 1 shows the different prices and price variability for different livestock types and Fig. 8 shows the herd composition in the study area.

Table 1: Lamb product prices and variability over the period 2000–2006

	Goats	Dorper	Karakul	Damara
Price lamb (30 kg)	250	311	299	299
Standard deviation	*77.7*	*40.9*	*24.4*	*24.4*
Price lamb (40 kg)	334	394	349	349
Standard deviation	*77.7*	*48.9*	*34.8*	*34.8*
Price pelt			329	
Standard deviation			*81*	

Prices are given in Namibian Dollars
Sources: Pelts - AGRA Namibia 2005 (time series of the last 15 years); lambs - Meat board data, MAWF 2000 to 2006

Veld types as units for management and transdisciplinary science

[S. Domptail & N. Dreber]

The environmentally heterogeneous Keetmanshoop region comprises a variety of distinct vegetation types and plant communities, each of them characteristic of a

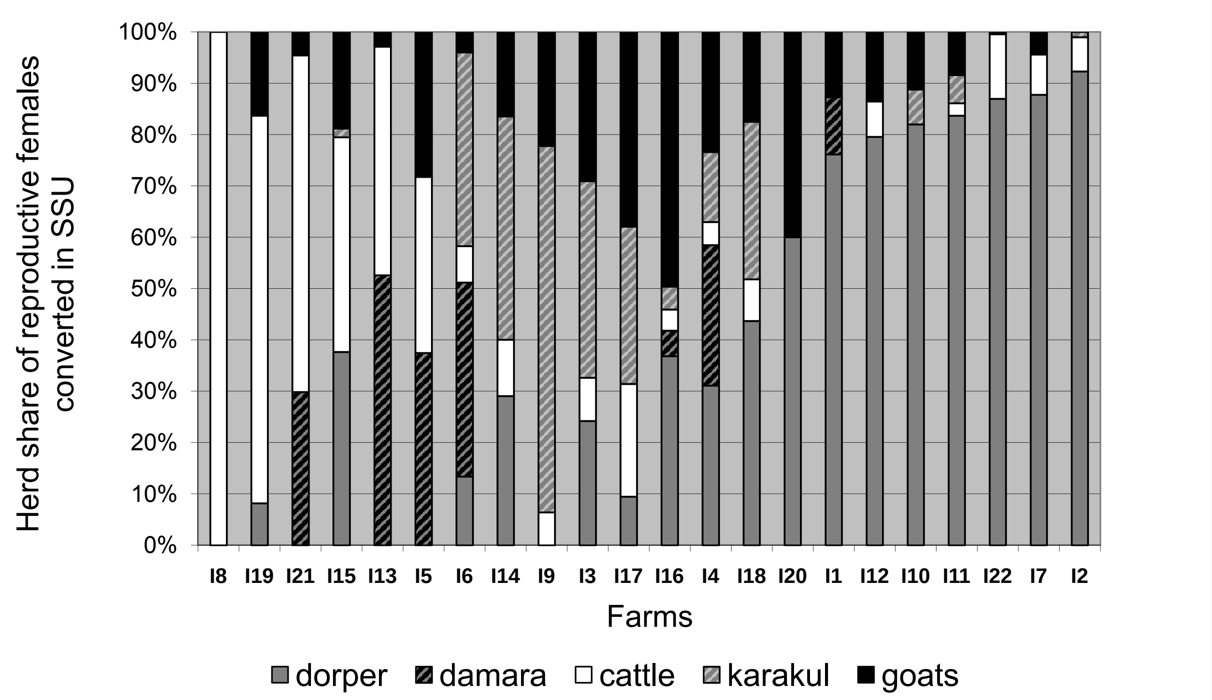


Fig. 8: Share of the different types of livestock in the herds of the 20 farms interviewed in 2005 in the study area (only reproductive females, converted in small stock units [SSU]). Graph: S. Domptail.

certain habitat defined by a set of geological, pedological, and topographical properties. A cultural domain analysis conducted within BIOTA among commercial farmers has shown that farmers in southern Namibia perceive this diversity and make use of it in their management strategies.

Results showed that farmers classify their land resources into distinct veld types using simple qualitative indicators of the abiotic and biotic environment (S. Domptail, unpublished data). They perceive veld types as entities with particular environmental characteristics such as topographical position, soil type, vegetation composition and structure (Table 2). In addition, distinctions between veld types are also made in terms of grazing value (i.e. the timing, the quality and quantity of fodder provided), carrying capacity and sensitivity to environmental impacts such as droughts and grazing. Within the whole interviewed sample, a total of seven veld types were identified by farmers (Table 2). Veld types often are delimited even on the small scale so that several veld types may occur on a single farm. Therefore, possessing a diversity of resources is perceived as highly valuable, as it supports a diverse fodder reserve in time and space. In this regard, veld types make specific contributions to the farming system and drive the spatial and temporal use of rangelands.

A main implication of this finding is that the concept of veld type may be very useful as a basis of communication between farmers and rangeland scientists as well as ecologists and conservationists to improve management, production, and conservation. Motivated by farmers' perception, we propose the hypothesis that ranching in the study area, where biomass variability is comparable only to that of the Namib Desert (MAWF 2004), is only viable because of this diversity. Access to key resources such as bossie veld and river beds (Table 2) is especially important since it enables farmers to better withstand the dry seasons in general and droughts in particular.

An attempt was made to establish a correspondence between a scientific concept of veld type classification and the farmers' perceived veld types in order to increase the knowledge on resource diversity in space for an improved management of rangelands (S. Domptail and N. Dreber, unpublished data). Therefore, a record and description of the resource heterogeneity in the Keetmanshoop area has been initiated in 2008 based on pedological and botanical mapping approaches.

The farms covered by the socio-economic study were also investigated in terms of the edaphic geodiversity (pedodiversity) existing in the study area. Grotehusmann (2006, Grotehusmann et al. 2006) conducted a soil survey in 2005 covering the most important geological and morphological structures in the area. A total of 61 soil profiles were examined and classified with the World Reference Base for Soil Resources (FAO 1998). Typical soils of the region included Arenosols, Calcisols, Cambisols, Fluvisols, Leptosols, and Regosols, most attributed as 'yermic' or 'aridic' in concordance with the dry climatic conditions (Grotehusmann 2006). Differences in e.g. soil texture, depth, and infiltrability are determining ecological factors for plant growth, and thus certain plant communities can be expected to be correlated with certain soil types. Consequently, in 2008, a pilot study was conducted recording the vegetation at the location of each soil profile examined by Grotehusmann (2006). Plant species composition and plant cover was recorded within 100 m^2 and 1,000 m^2 relevés according to the sampling design applied on BIOTA Observatories. Relevé-based environmental data was collected including aspect and inclination, and surface cover in percent of litter, stones, and bare ground on 100 m^2. In addition, soil was sampled to a depth of 10 cm for chemical and physical analyses (N. Dreber, unpublished data). A preliminary classification of veld types based on the pedological and botanical data revealed eight broad units frequently found in the study area (Table 2). The qualitative perception and assessment of veld types by farmers in the study area showed parallels to the preliminary veld types defined, but often lacked the understanding of the underlying causalities. Besides, the classification approach on the basis of ecological data provided a finer resolution in distinct entities, than the system perceived or used by farmers (Table 2). Though only a limited set of indicator species for each veld type is presented here, it is worth mentioning that farmers make use of a variety of taxa to differentiate between veld types and rangeland condition. However, in general farmers' knowledge of plant species was weak and frequently several names were used for identical plant species. This might also be due to the fact that guided botanical field trips are no longer organised by local farmer unions as in former years (Giel Steenkamp, pers. communication). This highlights the need for accessible and standardised information of the flora to improve communication among farmers and between farmers and researchers.

The ecological research on veld types is currently pursued with a refined classification of vegetation in the study area in order to define distinct phytosociological units and identify the main driving environmental factors for vegetation patterns. For this purpose, an area of about 1,800 km^2 was stratified into classes based on geological formation and topography using maps and satellite images. More than 200 vegetation-relevés (100 m^2 and 1,000 m^2) were assigned to these classes, and the same data set as in 2008 was recorded. First results revealed a total of 243 plant species from 54 families, and 12 vegetation units in the Keetmanshoop area, which are mainly separated by differences in soil depth, soil texture, lime content and inclination (J. Dorendorf, University of Hamburg, unpublished data). The work will provide a first phytosociological classification of plant communities in rangelands of the Keetmanshoop area, as well as environmental indicators and plant lists allowing stakeholders to identify standardised vegetation types and veld types, respectively.

Temporal and spatial landuse strategies of commercial farmers

[S. Domptail]

Short overview of current landuse strategies

The aim of management is to adjust herd size to the available biomass (Byers 1997), which in turn depends directly on

Table 2: Veld types and their characteristics as denoted by farmers in the Keetmanshoop region, and a broad classification based on ecological data

Veld type		Soil type		Habitat & vegetation		Indicator species	
Farmer	BIOTA	Farmer	BIOTA	Farmer	BIOTA	Farmer	BIOTA
Hard-veld (Torra, Vlakter)	Hard-veld (a) on dolerite	Hard & stony	Leptosols	Little vegetation, few bushes	Outcrops & rocky slopes; mix of trees, shrubs & grasses	*Stipagrostis anomala*	*Aloe dichotoma*, *Hermannia minutiflora*, *Triraphis ramosissima*
Mountain-veld	Hard-veld (b) on shale	Sandy-stony	Regosols & Leptosols	Plateaus & mountain sides; grasses & shrubs	Slopes, pediments & outcrops; diverse in dwarf shrubs & perennial grasses	*Petalidium linifolium*, *Monechma genistifolium*	*Hibiscus elliottiae*, *Setaria appendiculata*, *Indigofera pechuelii*
Bossie-veld	Bossie-veld on shale	Clayey & sandy, crusts	Leptosols	High bush cover, low-medium grass cover	Plains densely covered by gravel, often calcareous; dwarf shrub dominated	*Petalidium linifolium*	*Aizoon schellenbergii*, *Leucosphaera bainesii*, *Pteronia mucronata*
Soft-veld	Soft-veld (a) on dolerite		Regosols & Leptosols	Plains & small hills; grass dominated	Plains locally in contact to saprolite, often calcareous; species poor, much bare ground	*Parkinsonia africana*, *Rhigozum trichotomum*, *Tetragonia schenckii*	*Parkinsonia africana*, *Stipagrostis anomala*, *Zygophyllum rigidum*
	Soft veld (b) on shale		Regosols & Cambisols		Plains & moderate slopes dissected by washes; rich in shrubs, grasses & annuals		*Boscia foetida*, *Phaeoptilum spinosum*, *Lycium* spp.
	Grasslands on dolerite		Regosols (calcaric)		Plains, rich in silt & lime; species poor, mono-dominated by grasses		*Stipagrostis ciliata*
Lime-veld	Limeveld on dolerite	Stony & limy	Calcaric Regosols	Bushes & grasses	Plains, often underlying calcretes or lime nodules; species poor, much bare ground	*Zygophyllum* sp.	*Zygophyllum decumbens*
River beds	Riverbeds		Fluvisols	Bushes, trees & high grasses	Ephemeral river beds; dense, species rich vegetation	*Acacia erioloba*, *Stipagrostis namaquensis*	*Acacia erioloba*, *Stipagrostis namaquensis*, *Ziziphus mucronata*
Brak-veld		Salty		Flat		*Salsola* sp.	

rainfall and on the rangeland condition (ecological state). It is a dynamic problem, because herd and landuse decisions in a given year affect the herd and landuse options available in the next year. Thus, the high variability in rainfall and the related risks constitute the main challenge for farm management. Adjustment options include (1) the sale and purchase of ewes, (2) the purchase or production of supplemental fodder in the form of alfalfa pallets or corn, (3) increasing the output per lamb by retarding sale or slaughter, (4) and renting one's herd to another farmer. Another handling option is (5) to rest the rangeland (not use it), which improves the state of rangelands when rainfall conditions are favourable.

The recommended stocking rate for the area is about 1 Small Stock Unit (SSU; animal of 50 kg live mass) on 5 ha (MAWF 2005), but practices vary from 1 SSU on 10 ha to 1 on 3 (Domptail et al. 2009). Spatial farm management is based on rotational grazing. Indeed, fixed fences divide farms into landuse units called camps. Rotational grazing is the practice of moving animals from camp to camp following a grazing management scheme or biomass availability. The spatial and temporal allocation of animals to particular camps is the result of a complex decision process and aims not only at facilitating rangeland management. The allocation of livestock to camps is subject to constraints such practicability, location, and rangeland resources, as well as dependent on the breed or on special needs of livestock types (e.g. pregnant ewes). There are always tradeoffs among the fulfilling of constraints so that the strongest one on a specific farm will have a major impact on the grazing management.

Farmers resort to seasonal or whole-year resting and rotate the camps rested. Resting during the rainy season or in rainy years is critical for the regeneration and therefore the conservation of rangeland. Strategies for herd management in time

Table 3: Classification of behaviour according to farmer's actions in case of drought and extreme rainfall events (source: Domptail et al. 2009)

Behavioural category	Keyword	Behaviour description
Category 1	Threat avoider	Operating with land of high carrying capacity, but lower stocking rates; are very reactive to droughts (immediate herd reduction, eventually all animals can be sold or sent to another farm) and rather static in case of high rainfalls
Category 2	Opportunity seizer	Operating with land having a good carrying capacity, rather static in cases of drought (partial reduction in herd size, fodder purchase) and reactive to high rainfalls; indicators for rangeland management are based on vegetation
Category 3	Less flexible strategy	Rather static group, following a moderately tracking strategy (occasional purchase of fodder, low variability in animal numbers), with stocking rates sticking to recommended carrying capacity.
Category 4	Static strategy	Conservative and static strategy with maintenance of animal numbers, operating at rather low stocking rates (19 has a low stocking rate in absolute terms)
Category 5	Highly reactive strategy	Immediate adjustment in herd size by drought (all animal can be sold or sent to another farm) and high rainfall events (increase number of female lambs kept and purchase of ewes).

range from conservative schemes with low and constant animal numbers to dynamic 'opportunistic' schemes, where all control options are used to exactly match biomass and livestock in droughts as well as in times of abundance (Table 3). Importantly, landuse also affects the condition of rangeland, as is shown later in this chapter, and thereby its biomass production. This feedback is of key importance in the development of dynamic landuse strategies. Degradation risks associated with landuse options are known to farmers, although the amount of local knowledge varies with individuals.

Drivers and impact of landuse strategies

A series of hypotheses concerning the drivers of landuse strategies of commercial farmers in the study area were investigated. Potential drivers are (1) farm characteristics such as the average carrying capacity of the farm and the farm size, (2) farmer-related characteristics—the age of the manager/farmer, whether he is full time or part time farmer, his preference for rangeland conservation, and the indicators used to decide on the rotational grazing patterns on the different camps of the farm—as well as (3) economic factors such as product prices and fixed costs. Most factors were looked at on the basis of a correspondence table between the observed landuse strategies and farm/farmer characteristics. The impact of economic factors and farmer preferences for conservation on the economic and ecological outputs of farming activities was explored on the long term with the use of a bio-economic model parameterised for the study area.

Farmer related factors. Farmers use indicators as a basis for daily decision making in the allocation of animals and stocking rates to each camp. Vegetation indicators account there for 68% of the indicators cited and animal-related ones for 20%. Remaining indicators were related to other elements of the ecosystem such as soils and the presence of wild animals. Indicators range from the level of grass biomass to the observation of indicator plants (e.g. *Leucosphaera bainesii*, the 'Wolbos') (S. Domptail, unpublished data). Our results show a contra-intuitive trend with farmers practicing high stocking rates also using more vegetation indicators. Yet, one should recall that grass-dominated vegetation has a high productivity in comparison to other types of veld and thus farms dominated by grass veld have higher carrying capacities. No correspondence was found with the management types defined in the previous section. Thus, indicators used for the spatial allocation of stock by farmers would depend on the characteristics of the ecosystem rather than strategies chosen to cope with rainfall variations.

Farmers' occupation—whether part time or full time—may have an important implication for management since a parallel occupation generates income, which may be injected in farm management at times of need. Especially, we hypothesise that off-farm income reduces the yearly pressure to cover the fixed costs of the farm and households consumption. Results indicate that farmers benefiting from an additional income source adopt the most reactive (or 'opportunistic') strategies, strongly reacting to rainfall signals by selling a large share of their herd and purchasing livestock back again when conditions have improved. This can have either a positive or a negative impact on the rangeland, depending on whether livestock numbers remain coupled to the ecosystem or whether the access to markets (auctions) leads to a decoupling of the system and increase risks for degradation (Domptail et al. 2009, Müller et al. 2007). On the other hand, no pattern could be identified among strategies practiced by full-time farmers (S. Domptail, unpublished data). The role of farmers' preferences was not investigated empirically but rather via the analysis of landuse strategies simulated for the two objectives of rangeland conservation and income generation. The strategy aiming solely at income generation led to a much higher degree of degradation than strategies aiming at conservation (1/3rd of the farmland versus 1/10th; note that 100% conservation cannot be achieved due to the landuse-independent impact of rainfall). The trade-off between the two objectives increases with the achieved conservation level. Thus, when high stocking rates are practiced, small differences in stocking rates, which create only a small reduction in income, can have a large impact on rangeland ecology and biodiversity. This indicates that a potential exists to achieve a 'cheap' improvement in rangeland condition among some farmers providing appropriate incentives are used. At higher levels of conservation, differences in stocking rates become much more important in order to make a difference in rangeland condition (Domptail et al. 2009).

Farm related factors. Low carrying capacities affect the net margin per ha, since per ha costs—particularly high in rotational commercial systems—are independent of the land's productivity. Similarly, due to the importance of fixed costs, farm size may affect the economic viability of the farm. Critical fixed costs are the income desired by commercial farmers as well as annuities from the concentration of loans for a land purchase when it applies. Thus, these two factors may affect landuse strategies by increasing the risk perceived in the occurrence of drought events, which may in turn favor conservative (low and constant stocking rates) or threat-avoiding strategies. Results show that strategies used on land with a high carrying capacity (as announced by the interviewed farmers) tend to be dynamic. Both strategies which react strongly to drought as well as those which react primarily to high rainfall events are observed. A possible explanation to this rather contra-intuitive finding is that high carrying capacities are found on veld types dominated by a healthy perennial grass layer. Grass-dominated veld types on soft soils were found to be particularly sensitive to overgrazing and to drought (S. Domptail, and A. Popp, University of Potsdam, unpublished data), and therefore their management would require a strong reaction to either drought or high rainfall events, depending on the initial stocking rate practiced. The heterogeneity in rangeland resources is thus also a key criterion to understanding the diversity of farmers' strategies. Farm size appeared as an even more discriminating factor. As expected, a small farm size was found to correspond strongly to threat-avoiding strategies and may have important costs in the long term due to the 'forced' sale of animals during dry spells. On the contrary, farmers with large farms are able to keep low and constant stocking rates, thus minimising the costs of adaptation to rainfall variability, while still covering fixed costs (S. Domptail, unpublished data).

Economic factors. Economic drivers and stimuli to which the farming systems respond include household consumption levels and prices (of livestock, of inputs and of products). The yearly net income farmers need to generate for personal needs, education and debt reimbursement for the land, despite the impact of drought, can play an important role in stocking decisions. High costs may reduce the flexibility of strategies, as they constitute a disincentive to the reduction of herd size. Input prices, particularly of infrastructure, may play a similar role, when considering a farm of a given size. Further, high prices for livestock (productive ewes and rams), and especially a large difference between the income from livestock sales (usually in times of drought) and the costs of livestock purchase (after the drought) similarly constitutes a disincentive to adopt flexible and reactive stocking strategies with low levels of breeding. The ecological and economic impact of the level of household needs and of input prices was assessed by comparing long term computer simulated strategies. We found that when costs increase, the diversity in the possible strategies, expressed in the average stocking rates, is reduced. Stocking rates of income-oriented strategies decrease with increasing costs because the resource base (rangeland condition) must be maintained at higher levels to cover the costs on the long term, whereas stocking rates of the conservation strategy increase with increasing household needs, as can be expected intuitively (S. Domptail, unpublished data; Fig. 9). Thus, higher input, infrastructure, and household consumption reduce the flexibility of the farming strategies to adapt and react to different environmental conditions.

Prices of products on the other hand tend to affect herd composition, which in turn alters rangeland condition. Optimal herd composition, which satisfied the objective of maximal conservation, while maintaining minimum household consumption, was found to be composed of Karakul, Dorper, and Damara sheep as well as of Boergoats. Thus, the diversity of products (meat and pelts) as well as of grazing pressures (browsers vs. grazers) is important for the farming system. The optimal herd composition for conservation gives the Karakul sheep as the main breed of the herd. However, if prices for Karakul pelts drop below the threshold of N$250 (€22) per pelt, the proportion of the Dorper in the optimal composition overcomes that of the Karakul (S. Domptail, unpublished data; Fig. 10). In practice, when pelt prices are low, another more lucrative grazer breed should be brought into the herd. If not, there will be consequences either on the financial or on the ecological outcomes of the farming activity. These results are especially valid when uncertainty about rainfall is low. In a context of high rainfall uncertainty, Karakul skin production remains important, but the role of Damara sheep increases. Damara flocks are used as a buffer against the variability in biomass availability because of their low cost at purchase (S. Domptail, unpublished data).

Implications. Income sources and farm size both affect the dynamism of the stocking strategies. An increase in farm size reduces the strategy's dynamism while a diversification income sources increases it. The impact of these factors is also affected by a major constraint in a farming system, namely the fixed costs and household consumption which must be covered by every period of activity. Indeed, we found that for a given farm size, an increase in costs reduces the portfolio of possible different stocking strategies and makes it difficult to adopt veld friendly practices. This result is all the more relevant in the context of the land reform programme, as emergent commercial farmers contract important loans for the purchase of the land and also incur increasing input prices with regard to product prices. The means to alleviate this pressure were sought within the Affirmative Action Scheme (AAS), where loans are subsidised and the repayment of interests is deferred (Werner & Kruger 2007).

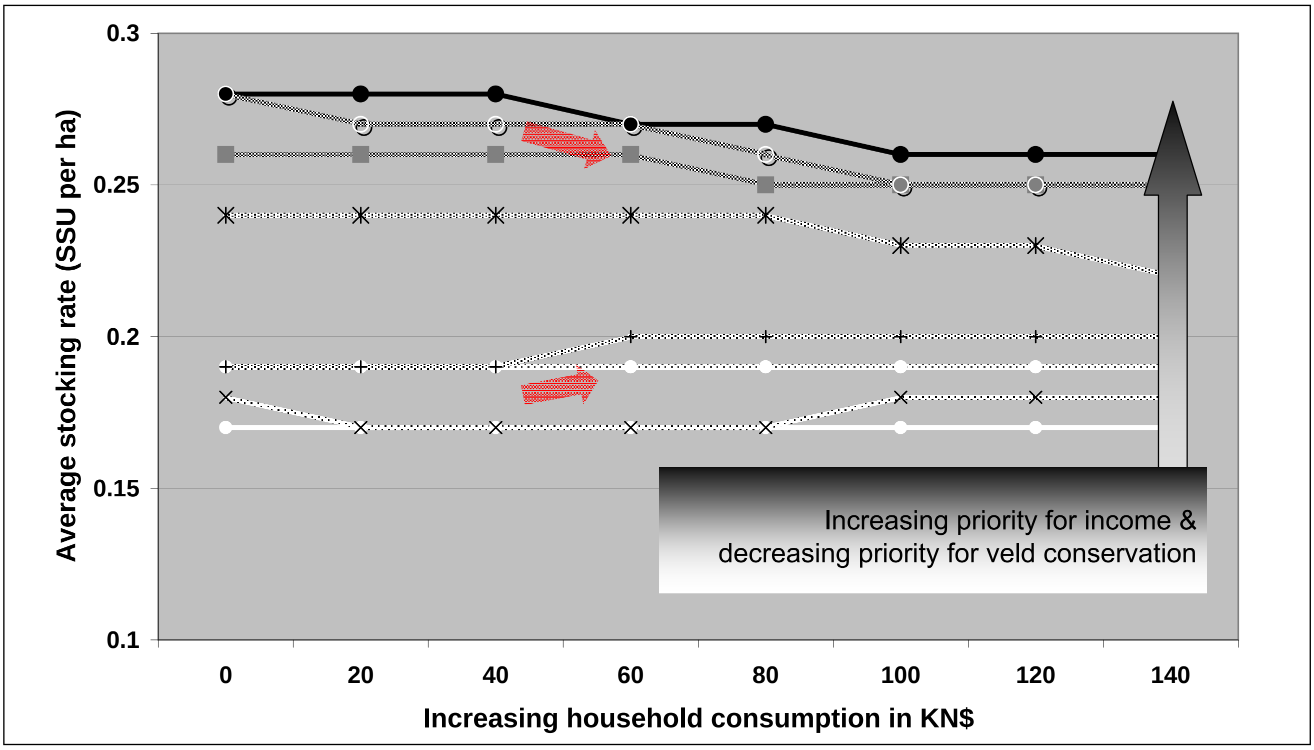


Fig. 9: Average stocking rates for eight different strategies with increasing preference for income generation over rangeland conservation objectives. Graph: S. Domptail.

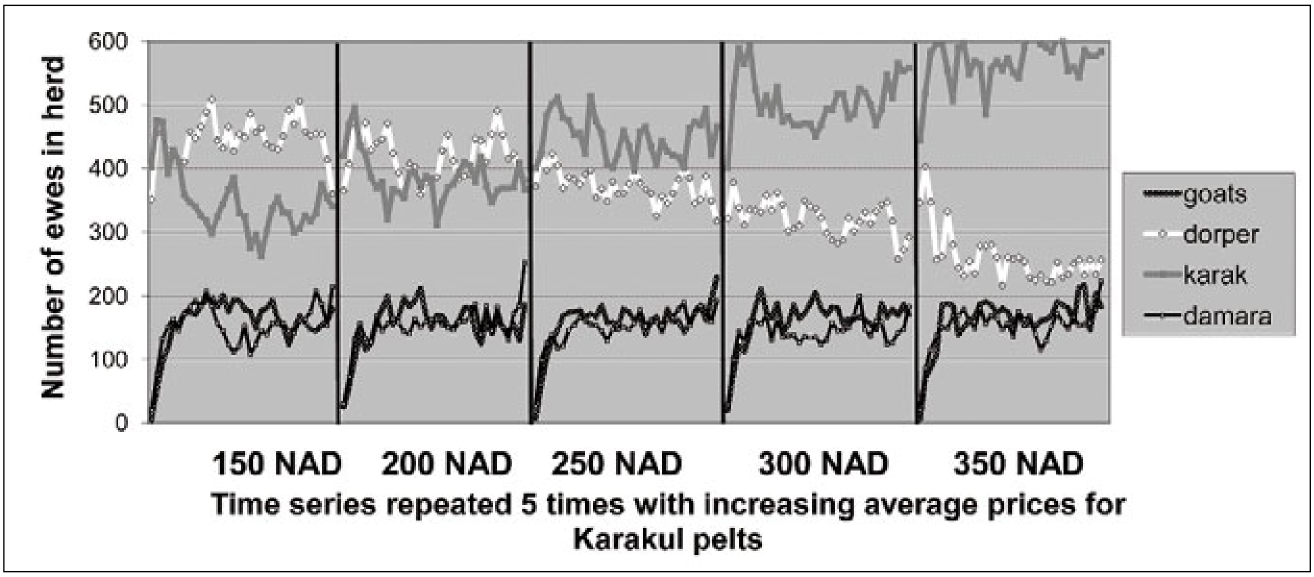


Fig. 10: Optimal herd composition for rangeland conservation under low uncertainty of rainfall and effect of Karakul pelt prices. Graph: S. Domptail.

Yet, our results suggest that the farming system based on high infrastructure costs may not remain viable. They call for innovative designs corresponding to the contemporary economic context and ecological insights. Concerning possible means to foster conservation, we found that a big difference in veld conservation can be achieved with slightly reduced stocking rates. This means that there is scope to encourage rangeland friendly practices, also at the political level through the use of well-targeted measures. An example is given in the next section on land tax design for rangeland conservation. Herd composition may also play a role in conservation, but results show that the suitability of the respective species depends much on prices.

Institutional solutions to foster conservation: the example of land taxes

[S. Domptail]

In the context of the land reform programme (Hunter 2004), land taxes have been designed and implemented in Namibia for all privately-owned agricultural land. Land valuation was carried

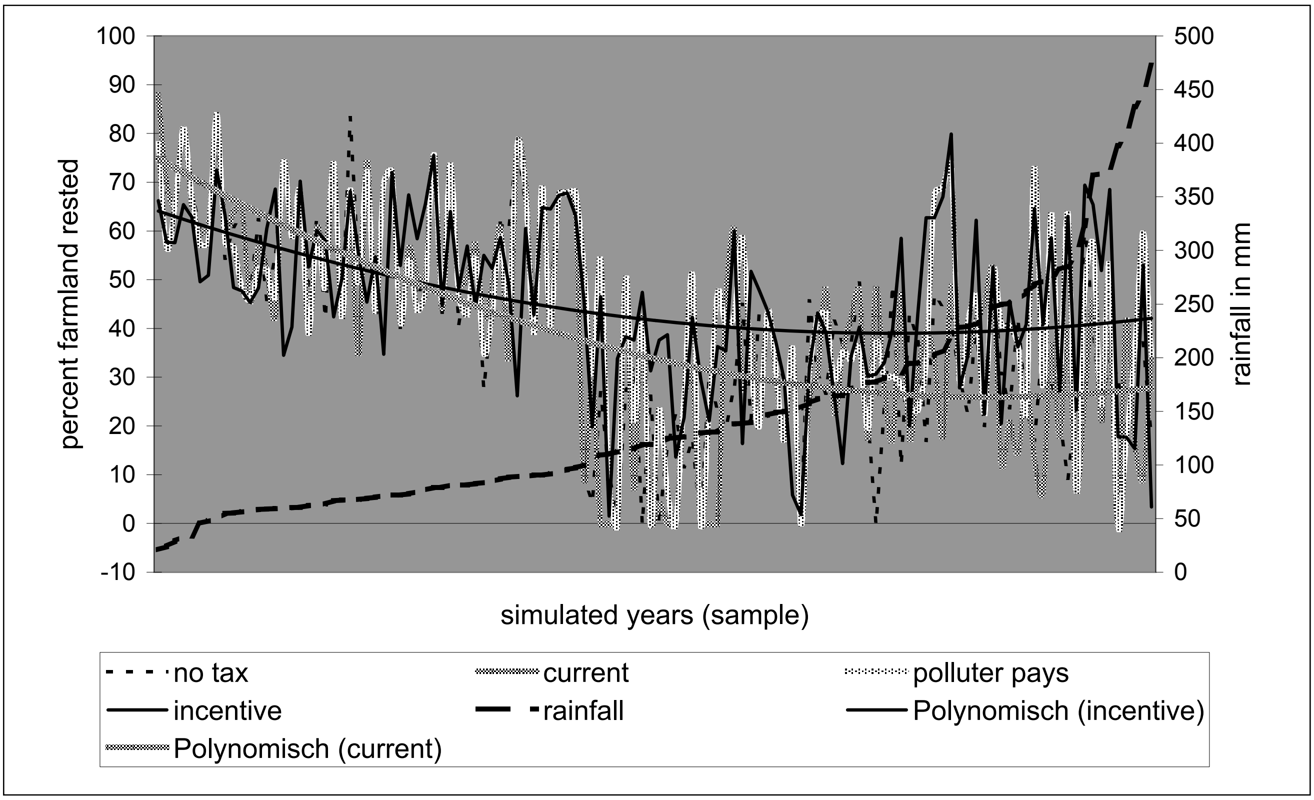


Fig. 11: Percentage of farmland rested (not grazed for a year) under each scenario and rainfall. Here we present only an illustrative sample of the 4,000 pairs of results obtained for the basic case where the rangeland is in initial good condition (from Domptail et al., in press).

out throughout the country to create a basis for the taxation. During the process of land tax design, concerns were raised about the financial burden that the tax represents. Will the tax lead farmers to change their farming strategies and would this change impact on veld management and veld condition? And especially, are there possibilities to use the land taxation system as tool to reward good veld maintenance or veld conservation? Answers to these questions were sought using a bio-economic model based on optimisation techniques and programmed in GAMS. Bio-economic models represent management decisions and the ecological dynamics of the veld. Rangeland ecology is incorporated in the model using the state-and-transition conceptual framework (Westoby et al. 1989).

First, our modelling results show that at the actual level, the fixed tax does not lead to a major change in farming strategies, nor does it have an impact on the veld condition. In a second iteration, an alternative design of the land tax was proposed. Based on the concept of payments for ecosystem services where environmental friendly practices are rewarded (Bulte et al. 2008), the design incorporated a tax waiver on farm areas in a healthy ecological condition. Practically, the scheme would function with regular on-farm assessments of the ecological condition of the farmland and its degradation status for each farm individually. This design may be proposed as a voluntary program: farmers who manage to reach high conservation levels get a bonus (the tax waiver), while others simply pay the due tax, as designed currently. In this way, farmers who suffer productivity losses due to degradation are not penalised (Buß 2006). This incentive design was compared to a design based on the polluter-pays approach, where all farmers pay the current tax, and farmers who degrade pay additionally for the damage costs. Results of simulation of the two taxation designs with the bio-economic model showed that both tax schemes create an incentive to increase conservation on the farm as compared to the scenario of the current land tax. This is especially the case in the incentive scheme, which achieves a reduction in the desertification of rangelands of 70%, while bringing in comparable income to the state as the actual tax scheme. Corresponding landuse strategies consisted of resting grass-dominated rangeland states, and adjusting herd size through purchases rather than by farm-breeding. Indeed, keeping a large proportion on ewe lambs is risky in a context of rainfall uncertainty because they stay on (and eat from) the farm for a whole year before they become productive. Adjusting herd size to the varying rainfall and biomass conditions by purchases and speculation appears more conducive to rangeland conservation. In addition, resting the land in time of high rainfall, which was found to have the most beneficial effect for rangeland regeneration (Müller et al. 2007) was also favored by the incentive scheme as compared to all other tax and to the no-tax scenario (Domptail et al., in press; Fig. 11).

To sum up, the land tax at its actual level would not lead to changes in the landuse strategies of farmers. The incentive tax design can bring the same amount of income to the state and foster on-farm conservation through its effect

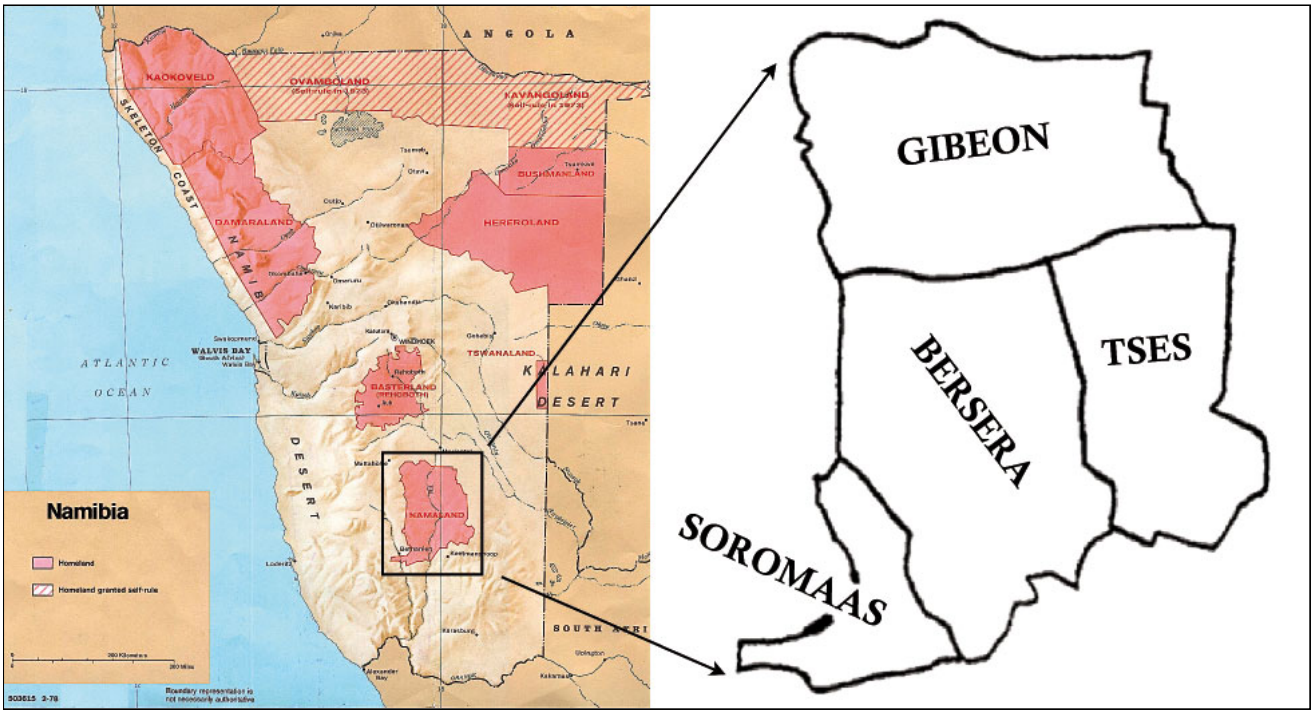


Fig. 12: Namaland in Namibia and their Administrative Districts. Adopted from Agricultural Office Keetmanshoop, cited by Klocke-Daffa (2001); map on the left side by courtesy of the University Libraries, The University of Texas at Austin.

on two key elements of the farming system: breeding versus speculation levels and resting practices.

3.4 Namaland: drivers of landuse in communal pastoralism

Livelihoods in the communal areas of Namaland

[T. Gibreel]

Background to the communal area

Namaland is a former homeland and occupies an area of 1,145,000 ha (Klocke-Daffa 2001). It is populated chiefly by the pastoral-agricultural Nama ethnic groups, who speak a Khoikhoi language. In 1963, the area was divided into five administrative districts, accommodating the major Nama clans (Fig. 12; Klocke-Daffa 2001). Communal areas occupy about 48 per cent of the total farming area of Namibia (Sweet 1999). This subchapter focuses on the Berseba district, home to the Goliath Nama-group in the south and to the Isaack Nama-group in the north (Klocke-Daffa 2001). The climate is arid, but well suited for sheep and goat production. Rainfall throughout the entire region is erratic and highly variable with a mean of 150 mm. It often occurs as isolated thunderstorms (Heyns et al. 1998). The main resource use activity in the communal area is small stock farming (Popp 2007).

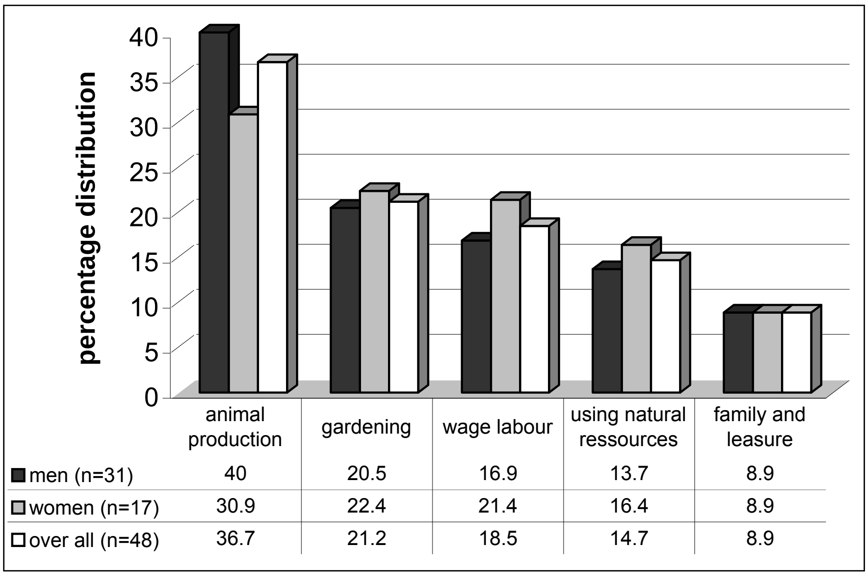
The production systems in Namaland are based on pastoralism and agro-pastoralism, and the majority of households is subsistence-based and labour intensive, and make use of little inputs and technology. The outputs and objectives of livestock ownership are much more diverse than in commercial livestock production and include milk, meat, cash income and capital storage as well as socio-cultural factors (Sweet & Burke 2002, Falk 2008). Communal farmers let their livestock graze near the homesteads and make use of available water at water points (Kuiper & Meadows 2002). Land is non-title deed in communal area (LEAD Project 2005) and the government is obliged to administer the land in trust for the benefit of traditional communities residing on such land [Republic of Namibia 1998: 11, 2002: sec. 17(1), cf. Falk 2008]. Most of the people who live on this land are in dire poverty (LEAD Project 2005).

The communal farming land is managed under a communal land tenure system wherein livestock movement in the area is not controlled, although there are unwritten rules of access and use which exist between different users. The land is overstocked (0.2 SSU/ha) (Popp 2007) and the veld is continuously grazed (Falk 2008), which has a strong impact on the rangeland resource (Popp 2007). This is in stark contrast to the management practiced on the neighbouring governmental research farm Gellap Ost, which has 160 camps, some of them are purposely under-stocked (0.05 SSU/ha). There, animals graze the camps within a rotational grazing system (Popp 2007, Falk 2008), which allows for resting periods (Kuiper & Meadows 2002).

Households' preferences, income sources and labour time allocation in the communal area

The data used in this section was collected by different BIOTA researchers through household surveys conducted during the period from 2001 to 2009 in the south of the Berseba district of Namaland. The investigated settlements are located from 25 km to 60 km north-west of Keetmanshoop and include Nabaos, Nuwefontein, Beespos, Tiervlei Kamelrevier, Snyfontein, Middleputs, and Uibes.

Twenty-seven households were surveyed in 2003 and 25 households in 2009. The average household size was found to be three persons (U. Schneiderat, T. Falk & B. Bock, University of Giessen and University of Marburg, unpublished data; T. Gibreel, unpublished data). Household heads were 54 years old on average, while male household heads were younger than female ones (53 vs. 64). In general, household heads obtained an average of 4.3 years of formal education, although the level of education of female household heads was significantly lower with only 2.6 years of formal education (B. Bock, University of Marburg, unpublished data).



	animal production	gardening	wage labour	using natural ressources	family and leasure
■ men (n=31)	40	20.5	16.9	13.7	8.9
▒ women (n=17)	30.9	22.4	21.4	16.4	8.9
□ over all (n=48)	36.7	21.2	18.5	14.7	8.9

Fig. 13: Results from the Conjoint Analysis divided into gender groups. Source: Bausch et. al. (2009).

Farmer's preferences were analysed by Bausch et al. (2009). Fig. 13 shows the preferences results for each livelihood element for a total sample of forty-eight farmers based on gender. In general, it was found that 36.7% of the farmers prefer the strategy of animal production as their major livelihood activity. Despite the adverse conditions for cultivation, gardening comes in the second place with 20.5% before wage labour, which takes the third position with 16.9%. Using natural resources and family and leisure claimed 13.7% and 8.9%, respectively. Principally, the female headed households showed different strategies from the average results of the conjoint analysis. They set great store by gardening and using natural resources. Households with the greatest availability of financial capital showed the highest values for gardening and natural resources using. The same result was found among the group of male-headed households benefitting from a state pension but with a weakened trend. Financial capital appears to be a decisive factor, which makes gardening more important.

Results from the 2001 and 2003 household surveys showed that a full-time job share in the average total income of the farmer was 61% followed by pension fund with the share of 25%, whereas results from the 2009 survey demonstrated that income from full-time job got the share of 29% in the average farmer's total income, but pensions transfers share was 8%. On average, the share of livestock sales in 2009 remained without change from the one of 2003 (5%). The small-enterprise and the remittances shares were found to be greater in 2009 (16% and 8%) than it was in 2003 (4% and 3%). The part-time employment share was larger in 2009 and accounted for 27%, while in 2003 it contributed only 1% (B. Bock, University of Marburg, unpublished data; T. Gibreel, unpublished data).

Concerning labour time allocation, we found that farmers allocated on average about 42% of their time on herding goats, 25% for off-farm work, 16% for grass collection, 8% for leisure and family, 6% for goats-kids rearing and 2% for home activities, while only 0.1% was assigned for firewood collection activity, although the estimated average collected firewood by a farm household for home consumption was found to be 2,400 kg per year (T. Gibreel, unpublished data).

Landuse driving factors

Goat keeping as a major source of sustenance characterises the economy of the whole Namaland communal area and particularly of the larger Tiervlei community. The concept of agricultural subsistence orientation (output-oriented) was adopted here to measure the extent to which farmers in the communal area consume from their goat produce in comparison to their marketed surplus, which may be represented by the agricultural subsistence (AS) ratio. The "*AS*" ratio, is the value of non-marketed agricultural produce over the total value of the agricultural production (Gibreel 2009). But, in this case study we calculated the '*AS*' ratio as the number of goats consumed divided by the total number of goats in the herd. As such, subsistence can be measured along a continuum from zero (total subsistence-oriented production) to unity (100% of production is sold).

The share of goat marketed surplus was found to be 26%, while home consumption of the own produced goats accounted for only 12% of the total average herd size (T. Gibreel, unpublished data). Goat off-take in 2003 was 17% only (Falk 2008). Thus, there is an increase tendency to sell more goats on the market. This results corresponds to national statistics of the Meat Board of Namibia (2010a, b) according to which the marketing of small stock increased by 4.73% from the end of 2006 to the end of 2007 due to increasing goat export. The goat export to South Africa, according to Agra Cooperative Manager for Small Livestock Pieter Hugo, has been overwhelming, thus the auction prices of a goat in the 30-45 kg range, fetched close to N$500 per animal (Fig. 14). Hugo pointed out that with the upswing in prices farmers, especially in the communal areas, had realised the potential in exporting goats (Ekongo 2005). Moreover, Namibian small-stock producers received on average a 25 per cent

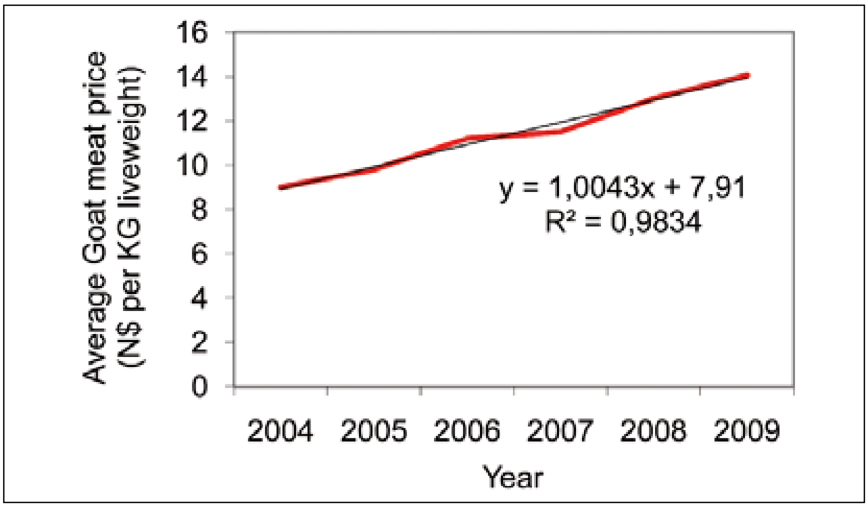


Fig. 14: Goat average auction price trend (2004–2009). Data source: Meat Board of Namibia (2010a).

Photos 2 and 3: Agra auction market in Keetmanshoop, southern Namibia. Photo: T. Gibreel.

increase in producer prices during 2006, according to Diana Mueseler, spokesperson of the Abattoir Association of Namibia (AAN) (Weidlich 2006). Because of increasing market price as shown in Fig. 14, farmers are encouraged to produce more goats to meet the export market demand. Consequently, increasing market-oriented goat production could be a double edge weapon in the sense that it may encourage intensive use of the rangelands to meet the export market demand, which can lead to rangeland degradation. On the other hand it may improve farmer's income by which he or she will be able to buy additional fodder for his or her livestock, which will have a positive impact on the range land by substituting the fodder from the veld with the additional supplementary food bought from the market.

On the demand side, farmers' consumption patterns explain their high dependency on markets. It was found that they allocate about 72% of their income to buy non-food and services goods from the market, whereas the rest of the budget is allocated for food goods. Furthermore, the total annual expenditure of farmers was significantly and positively correlated with the total number of goats which were marketed and although the number sold was small, the price they received was relatively high (T. Gibreel, unpublished data).

These results show that the farmers of the communal area are semi-commercialised rather than purely subsistent (Falk 2008) and that they decide simultaneously about their production and consumption patterns. Accordingly, farmers' consumption needs induce them to sell more livestock. Thus, farmers try to increase their herd size to gain enough income to fulfil their market goods and services needs. This hypothesis is supported by the existence of a positive and significant correlation between the numbers of does (female goats) owned per farmer and the time allocated to herding per farmer. This correlation suggests that farmers with large herds (encouraged by the market trends) allocate more time to grazing management, which means more control of the grazing pressure. In addition, it was found that weekend farmers allocated 206 hours per year while the part-time farmers and full time farmers allocated 585 and 1763 hours per year, respectively. This may have a positive impact for possible rangeland improvement as it shows that there is some knowledge and practice of grazing management among fulltime farmers especially (T. Gibreel, unpublished data).

In conclusion, farmers' consumption needs could be one of the drivers among others that provoke them to put more livestock in the market as well as to allocate more time for herding in relation to the number of animals marketed and the population of female goats.

Perceptions of communal farmers about past and future landuse

[B. Vollan & S. Domptail]

In the context of a full day participatory workshop in 2007, the main problems faced by the communal farmers and the solutions available to them, with a special focus on the role of the ecological state of the rangeland resources, were assessed among members of the Tiervlei community, in southern Namaland.

The careful choice of the method used for assessing problems of communal farmers is important since standardised questions are based on pre-existing knowledge of the researcher and thus might miss out certain aspects. Additionally, since the BIOTA project focuses on biodiversity, other important livelihood factors might be overlooked. Here we used a tool called "problem-cause-tree" aiming at identifying the main problems perceived by a person or a group, their causes and their visible consequences. Three groups were constituted among the participants, each producing a tree scheme. As a main problem the communal farmers identified poverty, which is evidently a multi-dimensional problem. The roots of this problem were perceived in the high unemployment rates, the lack of education, small herds, low rainfall, access to drinkable water, and the absence of savings or capital. The identified consequences included health problems, hunger, theft, little contribution to public or common goods such as the maintenance of water provisioning equipment, and finally degraded grazing lands resulting in low biomass and livestock production. An important insight in the discussion following the exercise was that effects of the problem will last until the causes of the problems are tackled. These findings may be understood in relation to the results of a survey conducted among the same farmers in 2004. According to those results, 81% of the farmers share the opinion that other issues are more important for farmers than resource protection and only 50% of them considered they knew how the environment could be better protected. Indeed, knowledge in ecology is rather limited: 95% of the interviewees believe that plants do not get extinct, but that they rather simply disappear temporarily and then reappear. Only 21% of the people know the carrying capacity of their grazing lands and 61% of the people share the opinion that the role of landuse on degradation is overestimated by scientists or politicians.

As the degradation of the rangeland is an important cause of the actual poverty problem of the farmer community of Tiervlei, the trend in degradation in time on their territory was further investigated. The farmers were asked to recall the ecological state of the communal rangeland during the last 40 years up to the 1970’s (Fig. 15a). According to them, the grazing land in 1970 was in a very good state, flocks of Kudus (*Tragelaphus strepsiceros*) and other antelopes were seen every day up to 5 times a day. The ecological condition of the rangeland has since then, and particularly since the late 1980’s, declined severely to the point that today one can hardly spot tracks of large game species. It seems to the farmers that if the trend continues, antelope will have vanished from the communal area in 20 years time. Farmers mentioned that one of the drivers of land degradation was the fodder subsidies, which were granted to communal farmers during the drought relief program, which was in place until independence in 1990 (pers. communication A.S. Kruger 2010). The program enabled farmers to maintain large herds during drought periods and especially after the drought, when the rangeland regenerates after the first good rains. The second driver mentioned was the in-migration of several families in the area, which generated a stronger grazing pressure on the land. Farmers associated this development with a ’weakening’ of the traditional authorities of the Namaland, who regulate land access, or to an increasing pressure from poverty and the subsequent need for land to sustain livelihoods. It might also be due to the proximity of the Tiervlei community to the city of Keetmanshoop, thus attracting many so-called “weekend-farmers”. The intensity of the pastoral activity also showed an important decline co-incident with an increase in rangeland degradation. Farmers stated that 20 years ago (ca. 1987) the largest farmer still had five times as much livestock as the largest farmer of the Tiervlei area today, who has only 200 animals today.

The fact that farmers with up to 500 animals were practicing transhumance in more remote and less degraded areas (B. Vollan, unpublished data) supports the hypothesis that proximity to Keetmanshoop and the absence of seasonal mobility affects the ecological status of Tiervlei’s rangelands. In addition, scientists and local experts were consulted on their view of the high degree of degradation evident in the region. Their answers suggest that a combination of the drought relief program (pers. communication A.S. Kruger 2010) together with a severe drought from 1979–1986 might have led to both the severe degradation and the consequent reduction in livestock numbers (Schönherr 1989). Fig. 15 with illustrations evolved during the participatory workshop in 2007 shows the long dry spell mentioned by Schönherr (1989). Since 1992, the Namibian Government has promoted the marketing of livestock in drought periods but there has not been any positive significant change in the state of the rangelands. As mentioned below, it might take decades and an important rehabilitation effort to improve the ecological state of the rangelands to their initial state. Fig. 15a shows the perceived trend in ‘veld’ condition as well as the parallel trend in livestock numbers, which do not seem to be driven by an equally decreasing rainfall trend Fig. 15c. It was also mentioned by the farmers, that there high rainfall events have declined over the past 30 years. This observation is in line with the rainfall data from Gellap Ost that shows the absence of major rainfall events between 1979 and 2006. The absence of these major events combined with high stocking rates might have prevented the recovery of the grazing area.

Finally, the last discussion of the workshop revolved around the possible paths for improvements of the livelihoods in the community. During the initial brainstorming sessions, farmers named as a possible solution the establishment of a conservancy in the whole Berseba district of the Namaland. This idea has been in process for seven years but is blocked at the moment due to conflicts among Nama groups about the size and benefit-sharing of the planned conservancy. Second, the establishment of fenced camps was mentioned, with the aim of enabling the practice of rotational grazing, as well as to prevent others from entering the area. An increase in productivity through the use of livestock of higher quality for breeding was also mentioned. Lastly and most importantly, the community aimed at getting involved in tourism through the construction of a campsite and by proposing tourist activities such as for example hiking in designed botanical trails, horse, and donkey rides. The vision included game watching as an important activity, motivating the reestablishment of Kudu (*Tragelaphus strepsiceros*) in the area for the benefit and pleasure of both farmers and tourists. Notably, the reduction in stocking rates was not mentioned as an element of solution. This is congruent with results of a previous survey conducted in the same area according to which a reduction of the number of livestock is not an option for most farmers even in times of drought. Importantly 44% of the farmers stated, that they would or could do nothing to prevent the overuse of rangelands (Vollan 2009).

To sum up, the diversified and positive visions of the community for their

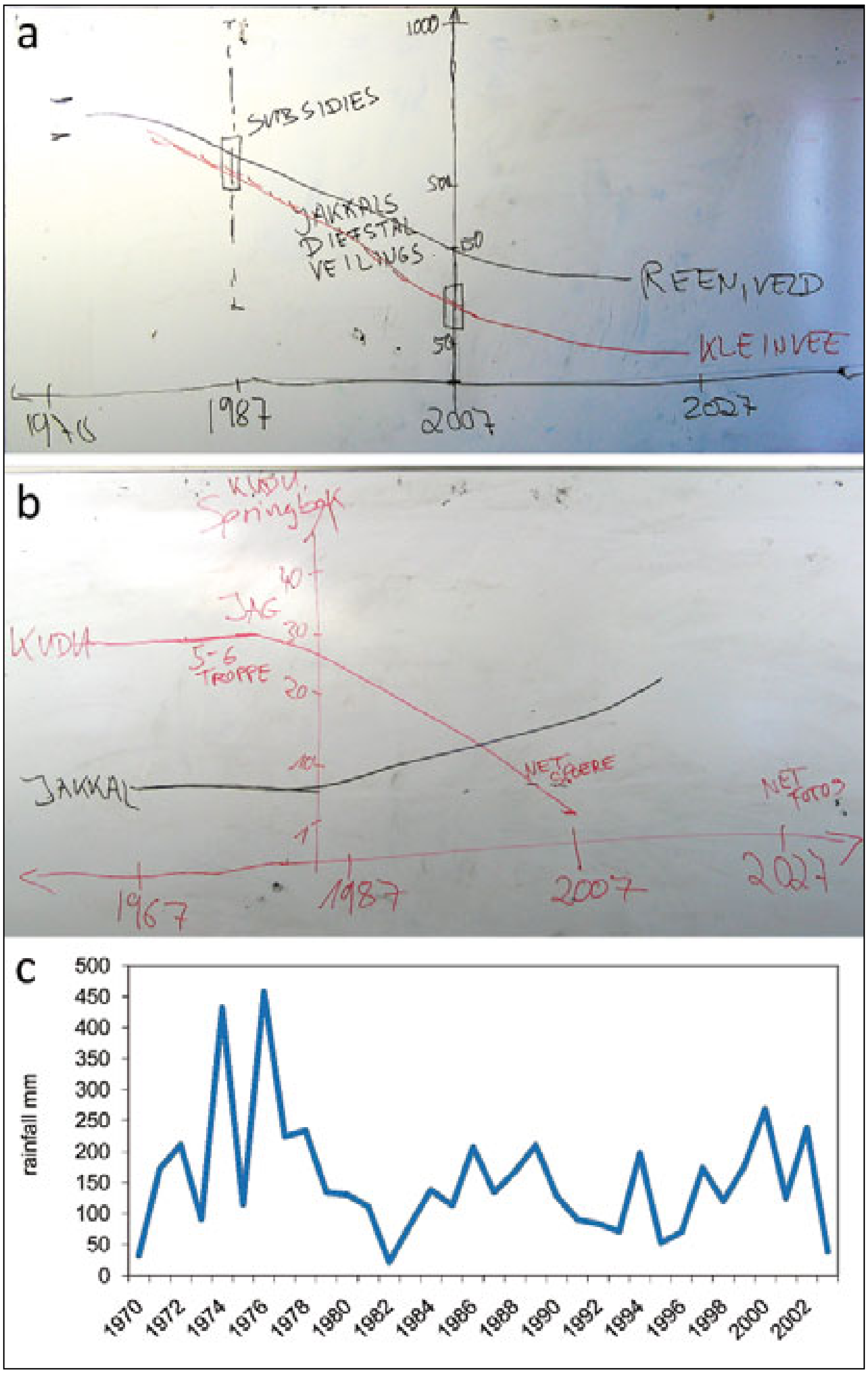


Fig. 15: Ecological condition. a) and b) reconstitution of the past rangeland ecological condition; c) rainfall at neighbouring farm Gellap Ost from 1970 to 2003 (data: Gellap Ost). Photos a & b: B. Vollan 2007.

livelihoods and lands show that the community is eager to implement any beneficial project which is both ecological sustainable and generates income. While degradation has been shown to be a main root of the poverty problem encountered in the communal area, a reduction in livestock densities seems unlikely to occur. This is highly problematic, as any restoration effort is likely to fail without reduced livestock numbers and/or a sustainable grazing management. As a result, the political focus should be put on the improvement of access to basic resources such as secure lands and drinkable water as well as on the development of alternative landuses or of additional incomes sources. A pre-requisite for the implementation of any solution in the communal area is good governance and cooperation. Drivers of cooperation are investigated in the next section.

Is lack of cooperation in the commons a driver for ecological processes and the missing key to sustainability?

[B. Vollan]

The environmental awareness among the interviewed farmers in the communal area of Berseba is extremely high and people know that they are affected by environmental degradation. The same is true for the intention of people to act to protect biodiversity or the environment (Vollan 2009). However, there is a discrepancy between what people would like to do and what is actually achieved through local institutions. Given that most people feel affected and intend to do something against the advancing degradation, why do people still fail to take action for the conservation of their environment?

We have argued above that a degraded area might take decades to recover and that rangeland in a healthy state would benefit from cooperative farming practices. Also, in drought periods it might be beneficial for farmers to collectively reduce their stock. A unilateral reduction of livestock by a single farmer would not be effective ecologically and would economically harm the individual concerned. Thus, it is important that a reduction in herd size is decided collectively, for the benefits of the whole community of farmers. This so-called social dilemma between individual and collective rationality is recognised by many practitioners, which is why appropriate veld management practices in communal areas need to be based on the coordination and cooperation among farmers. This view is also shared by communal area farmers themselves with more than 50% of the interviewed farmers believing it is possible to practice rotational grazing in communal areas. Almost 40% see the lack of co-operation between farmers as a main problem (pers. communication with A. Lourens, Dept. of Agriculture, Namibia, 2004). Similarly, 77% of all interviewed farmers would accept a limitation of stocking rates and 43% a prohibition to harvest firewood should such a decision be made collectively. Also, 65% of the farmers notice that co-operation increases their own personal benefits and agree that they would get more money from farming if they and everybody else would reduce the amount of animals that utilise the rangeland. However, the widespread poverty together with a lack of sound institutions in the communal areas makes 65% of the farmers, state that they are planning to increase their stock of animals. Given the perceived need for cooperation and the observed failures to reach cooperative solutions, one important question is how farmers change institutional rules and how does this relate to their own experience with the environment. This research questions was explored by using a method of economic field experiments that mimic such a social-dilemma situation (B. Vollan and S. Prediger, unpublished data).

In the context of a workshop held in Keetmanshoop (2007) we let communal and commercial farmer as well as other stakeholders from government and non-governmental organisations and scientists from various disciplines participate in this experiment. All participants realised the difficulty of cooperation in the experiment and saw the similarities between the experiment and the communal farming system. Backed with that experience, almost 70% of participants chose the rotational rule to solve the dilemma among three possible rules (property rights, rotation, and regulation of stocking rates) that could all work equally well to establish cooperation. According to Fig. 16 the rotational rule was perceived to be the fairest rule. Participants also realised that their personal freedom was higher with the establishment of well-defined property rights and that regulation would have been more effective. However, these features seem to be less important than fairness (Fig. 16). In our experiments with communal farmers in Namibia and the Namaqualand we found similar results with 50% of the people voting for rotation rule and only 20% the regulation rule (which is already in place in Namaqualand) (Vollan et al., unpublished data). Since it is more likely that laws and regulation work well if they are supported by the community and the involved stakeholder one could try to build on this shared perception. From other co-management arrangements one could draw the lesson that the rotation rules would need to be enforced by an external agency while the monitoring of the rule would be the task of the community.

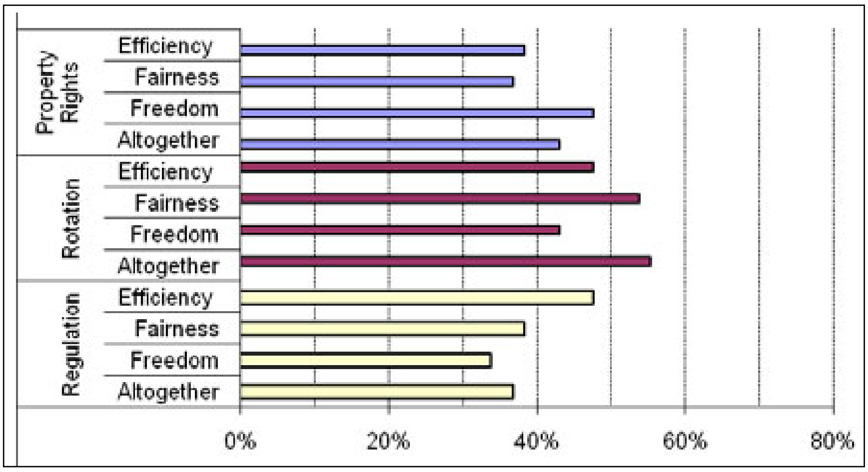


Fig. 16: Perception of different rules. The rotation rule is perceived to be the fairest rule. Graph: B. Vollan.

Potentials and limitations of communal conservancies in southern Namibia

[S. Prediger & M. Kirk]

Introduction

Since independence in 1990, the Namibian government has gradually begun to devolve authority over natural resources to local users. These so-called community-based natural resource management (CBNRM) approaches have received considerable policy and research attention in the last two decades and encompass forest, game, and water resources. The most popular CBNRM initiative in Namibia is doubtlessly the communal conservancy approach on which we focus in this article. The conservancy approach attempts to combine both wildlife conservation and economic development, aimed at the improvement of local livelihoods through the sustainable use of wildlife resources and an increase of environmental awareness among local resource users.

Since the establishment of the first conservancy in 1998, no less than 59 conservancies have been registered until October 2009, covering 133,092 km² of Namibia's surface area. A further 25 communities are currently in the registration process. Annual income generated by these conservancies has risen from less than N$1 million in 1998 to about N$32.45 million in 2008 (NACSO 2008). Moreover, wildlife populations in the communal land, including the populations of endangered species such as the Black Rhino (*Diceros bicornis*) or the Desert Dwelling Elephant (*Loxodonta africana africana*) have increased significantly over the last decade (NACSO 2008). These encouraging records suggest that conservancies can have a substantial positive impact on resource protection, biodiversity preservation, and local livelihoods. So far, however, most registered conservancies are situated in the relative wildlife-rich northern parts of Namibia, in particular in the Kunene (20 conservancies), Caprivi (11 conservancies) and Otjozondjupa (8 conservancies) region. Detailed case studies on the impact of conservancies on local livelihoods have almost exclusively been conducted in these regions (e.g. Bandyopadhyay et al. 2008, Barnes et al. 2002, GTZ 2006). An important unresolved question is thus, whether conservancies can also generate considerable income in areas where wildlife resources are rare and wildlife-based tourism potentials are relatively low, as in the Nama Karoo biome in the Karas region. In addition, it is also important to know whether conservancies provide an additional (or even alternative) landuse option to exclusive small-stock livestock farming, which, at present, constitutes the main livelihood strategy in the communal areas in the southern Nama Karoo. In the following, we will address these questions.

Fig. 17: The !Khob!Naub conservancy. Source: NACSO 2008.

Legal framework and aims of conservancies

Conservancies are legally gazetted areas within the state's communal lands which enable rural communities to gain consumptive (e.g. trophy hunting, live sell) and non-consumptive (e.g. safari-tourism) wildlife use rights, provided some obligatory requirements are fulfilled. According to the 'Nature Conservation Amendment Act' of 1996, the registration of communal conservancies requires the elaboration of a local constitution, clearly defined boundaries of the conservancy area, the election of a representative committee plus a plan for the equitable distribution of benefits to the conservancy members and sustainable wildlife resource management (for a detailed description of the legal framework of conservancies see Corbett & Jones 2000, Jones & Murphree 2001). The conservancy initiative mainly aims at the improvement of local livelihoods and the preservation of biodiversity. Through the establishment of a conservancy and the subsequent devolution of rights to use and benefit from wildlife, local communities get incentives to manage their game resources sustainably and therefore to conserve biodiversity. Another goal which is often expressed by representatives of NGOs and politicians is the promotion of gender equality and democratic structures at local level. Conservancies thus try to serve a wide range of partly contradicting objectives, entailing the danger of trade-offs and conflicts in implementation and management.

Communal conservancies in the Nama Karoo in southern Namibia

There are four communal conservancies in the Karas region, which is the southernmost administrative unit in Namibia. By the end of 2001, residents from settlements in the eastern part of the communal land of Berseba and the communal land around Karasburg had began to prepare the formation of the first communal conservancies in the Karas region, which eventually became registered in July 2003 under the names !Khob!Naub and //Gamaseb respectively. Another two communities (!Gawachab and !Han /awab) followed suit and established conservancies in 2005 and 2008. The //Gamaseb conservancy has had considerable problems in the last few years. The former committee consisted of members who were partly illiterate and who had no proper management experience. Information was not shared with ordinary conservancy members, the disposal of funds was not transparent and they were accused of being corrupt in their activities. We were thus recommended by U. Davids (Namibian Development Trust, NDT), the head of the local CBNRM-supporting NGO, to conduct research rather in the !Khob!Naub conservancy, which is according to him the most successful conservancy in the south. The !Khob!Naub conservancy (Fig. 17) is situated northwest of the Nabaos BIOTA Observatory and extends over an area of 2,747 km². The northern part is dominated by the plateau after which the conservancy is named, while the eastern and western parts are flat grasslands (NACSO 2006). The area is mainly populated by Nama people and is home to approximately 5,000 people.

Survey results

To investigate conservancy members' and non-members' personal perceptions of and experiences with the !Khob!Naub conservancy, we interviewed 54 residents, of which 35 were conservancy members, and two committee members in June 2008, 5 years after the conservancy was registered. All data reported here are taken from the survey and personal interviews (S. Prediger, unpublished data).

The conservancy establishment itself was expedited by traditional authorities and M. Cloete in collaboration with NDT, the main local support agency, and the Ministry of Environment and Tourism (MET) in Keetmanshoop. Cloete has been the chairperson of the conservancy ever since its inception, and was confirmed in office in recent elections held in 2009. The conservancy committee consists of seven men and four women and is elected by the registered conservancy members. The committee aims at representing different interests within the community and thus consists of farmers and non-farmers, representatives of the traditional authorities and of other CBNRM initiatives, such as the community Hoodia (ghaap) nursery and the water point association. Cloete defines the main functions of the committee as being the management of the conservancy, including budgeting, attraction of funds, the implementation of conservancy-related projects (e.g. the campsite project), and information-sharing with the conservancy members as well as the improvement of environmental awareness. The committee members do not receive a salary for their efforts although only an allowance of N$65 is paid to them when they attend committee meetings, which are held every second month. To compensate them for travel costs, members additionally receive a mileage allowance of N$2.5 per km.

Any person living or farming in the !Khob!Naub area can become an ordinary conservancy member and any registered conservancy member can run for committee membership. Initially, the registration was free of charge but since 2008 registered members have to pay an annual membership fee of N$20. In November 2009, 60 villagers were registered as conservancy members according to official records, compared to 56 at the time when we conducted our survey.

Information sharing is an essential precondition for participatory initiatives like conservancies. Once a year, a general meeting for all conservancy members and non-members takes place. At these meetings, the committee provides members with the latest information about game count results, the financial situation, proposed appropriation of financial revenues from game utilisation and the budget for the next year. About 80% ($N = 50$) of the interviewed members stated that they attend these meetings regularly. However, most interviewed members receive information mainly in the conservancy office in Blouwes or through personal discussions with committee members. When asked whether the interviewees felt that committee members provided them with sufficient information about conservancy progress, we found mixed results. While more than 50% answered “yes”, about 40% felt that they were insufficiently informed. Because some respondents who lived far from Blouwes complained that meetings are held disproportionately often in Blouwes, we used multivariate regressions to investigate whether the location of residence or other covariates can explain the heterogeneous judgements. None of our results supported this hypothesis. The results show, however, that the provision of information could be improved. This is not a particular problem of the !Khob!Naub conservancy, but rather seems to be a general problem faced by many conservancies [U. Davids (NDT), R. Malone (Namibia Nature Foundation, NNF) and U. Hdjavera (Namibia Community Based Tourism Assistance Trust, NACOBTA), personal interviews]. Another frequently reported problem with respect to information sharing pertains to the refusal of former committee members to teach their successors in accounting and other management skills acquired during the training.

Expectations, judgements, and benefits

When we asked conservancy members what prior expectations they had on conservancies before they became members, most named job creation (46%) or meat distribution (33%) while about 20% awaited either better environmental knowledge or game protection. So far, however, only 50% of all respondents were the opinion that their expectations were fulfilled. Nevertheless 86% ($N = 50$) stated that they or their household benefited directly from the conservancy, and when only the responses of conservancy members were considered, the fraction was even higher (94%).

Tangible benefits include salaries and meat distribution. There are eight persons, who receive a permanent monthly income from conservancy activities. These include one coordinator, who is responsible for several administration tasks and who receives N$1,000 per month, and seven game guards who earn N$250 per month for monitoring wildlife. The expenses for salaries and the allowances granted to committee members cannot be covered by conservancy revenues yet and are subsidised by the integrated community-based ecosystem management (ICEMA) program. More jobs are expected to be created in 2010, when the recently constructed community campsite will be launched. The committee has applied for funds to employ three campsite caretakers and a tour guide, but to date they have been unsuccessful in their applications. Aside from wage labour, a substantial fraction (34%) of conservancy members has been working voluntarily for the conservancy. Typical examples for voluntary work are the assistance at game counts, monitoring and hunts, kitchen work to prepare meals at workshops, as well as the provision of private assets (e.g. car or fridge) for conservancy purposes.

Benefits enjoyed by all conservancy members are the annual meat packets distributed among them. Since 2005, the MET has granted hunting quotas to the conservancy. The size of the quota depends directly on the population size of key game species, which are estimated according to annual game counts. The MET, NDT and conservancy members conducted these counts jointly. So far, only Springbok (*Antidorcas marsupialis*) have been allowed to be hunted. The quotas for springbok have varied in the last 5 years and have ranged from 62 animals in 2006 to 250 in 2008 and 2009. Except in 2005, the quotas have been used solely for own consumption, that is for meat distribution among the conservancy members. Quotas have also not always been exhausted. When we visited the conservancy in November 2009, for instance, only 38 springbok had been shot, due to the lack of necessary equipment and assistance from MET. The vast majority of interviewees (67%) saw the annual meat distribution as the main benefit of conservancies at household level, while job creation was only named by one respondent. Six people did not see any benefit at all, although five of these respondents were not conservancy members.

Interestingly, about 18% of the respondents felt that improved knowledge about wildlife protection and community empowerment were the most beneficial aspects of the conservancies. This shows the importance of non-material benefits of conservancies, such as pride and empowerment, which has also reported in studies carried out in other conservancies (e.g. Ashley 1997). It became further apparent that the respondents attach high value to the growing number of wildlife, as roughly 95% said that the reintroduction of formerly extinct or rare species, such as Oryx (Gemsbok; *Oryx gazella gazella*) and Kudu (*Tragelaphus strepsiceros*), make them proud. The fact that about 40% of the respondents felt that they were willing to reduce livestock numbers if this was necessary for the reintroduction of game, further highlights the importance some people attach to the existence of wildlife in their area, although this question might be prone to hypothetical bias or surveyor effects.

Another important aspect of conservancies is the equitable sharing of benefits among members. In our study, 73% of the conservancy members were the opinion that benefits are shared equally.

Finally, we asked the respondents whether they see any disadvantages of the conservancy to either them or the community. While the vast majority felt that there were no disadvantages, about 18% of the respondents (15% if only conservancy members’ answers are considered) saw disadvantages. Most of these respondents criticised the size of meat packets allocated to them, the frequency of meat distribution (only once a year) or the fact that they cannot keep the meat fresh because they do not have a fridge. One respondent (who was not a conservancy member) complained about the prohibition of hunting with dogs, which is now of course illegal. None of these complaints, however, could be considered to be disadvantageous in the strictest sense of the word.

Discussion and conclusions

Do conservancies contribute to habitat and biodiversity protection?

Perhaps the most important questions with respect to conservancies in southern Namibia are (1) whether they can serve as an additional or even alternative landuse option and (2) whether they can contribute to biodiversity preservation. We will first discuss the impact of conservancies on biodiversity protection and then focus on the potential of conservancies to serve as an alternative landuse option.

One main benefit which has resulted from the establishment of the conservancy is the increase in wildlife populations and the increased diversity of game in the area through the introduction of rare species and the reduction of poaching. However, the main anthropogenic drivers of biodiversity loss in communal areas are not poaching, but continuous overgrazing and the collection of firewood, which both cause degradation. While poaching is directly tackled in the conservancy approach, overgrazing is not! A first step for comprehensive biodiversity protection, at least on a small-scale, would be the declaration of zones exclusive to wildlife where livestock keeping is prohibited. The! Khob!Naub conservancy has been discussing the establishment of an exclusive game area since 2007, but has not reached an agreement, yet. Problems are the costs of fencing-off the area and the necessary compensation and allocation of alternative grazing areas, respectively, for farmers who graze livestock in the proposed wildlife area. However, as long as stocking rates are not reduced within the existing management system, it is unlikely that conservancies will be able to contribute substantially to biodiversity preservation.

Conservancies as an alternative landuse option

While some conservancies generate substantial revenues, which are high enough to cover running costs and to supplement their members' annual incomes, most still depend on external funds and might never become financially independent. Of the 53 conservancies that were registered in 2008, 38 earned cash income and 34 of them at least contributed to their own operational costs. However, among these 34 conservancies, only 14 were able to cover all their costs while 11 contributed more than half of their operational costs (NACSO 2008). Altogether, 257 people were employed by conservancies in 2008 and 154 of them were entirely funded by the conservancies themselves (NACSO 2008).

The main drivers of conservancy revenues and employment are joint venture lodges, which accounted for N$17 million or 56% of total revenues, followed by (joint venture) trophy hunting (25.4%) (NACSO 2008). However, the potential for trophy hunting is comparably low in the communal areas of southern Namibia, where only springbok have large enough populations, which can be hunted. Springbok, however, are not a highly-prized trophy species and do not compare favourably in this regard with animals such as Kudu, Oryx, and other large antelope species as well as premium trophy animals such as the Big Five, of which bigger populations only occur in the north (C. Weaver, WWF, pers. commuication). Moreover, most trophy hunters come from overseas and usually expect "luxury" accommodation, which is not available in any conservancy in the south. The MET has been looking for private hunting operators who are willing to obtain a hunting concession for the !Khob!Naub area, but to date has not been able to find any interested party. Similarly, joint venture lodges have been launched in either relative game-rich regions and/or in areas with spectacular landscapes, often close to tourism "hotspots" like Etosha, the Kaokoveld or the Brandberg. Unfortunately, the! Khob!Naub conservancy does not constitute such a place.

In our survey, 96% of the respondents expected more jobs and higher financial benefits generated by the conservancy in future. Most expect the recently established campsite, which was funded by the EU and cost N$ 350,000, to foster development. Though the campsite is close to the B1 highway and thus easily accessible for tourists, it is unlikely that it will generate high revenues. First, conservancy campsites accounted for only 2.7% of total conservancy revenues in 2008 (NACSO 2008). Many campsites also suffer from poor infrastructure (e.g. no electricity or accessible water) and, perhaps more importantly, a lack of marketing. This makes community campsites rather interesting for backpacker and/or low-budget tourism users only. Second, lessons drawn from the Brukkaros campsite, situated close to the !Khob!Naub conservancy, indicate that tourism potential is rather low in the communal areas in the south. The Brukkaros Mountain is a beautiful place offering its visitors a spectacular and scenic view. Despite its beauty and location, however, overnight visitors are rare, and entrance fees are not sufficient to cover the salary of the caretaker, which is still subsidised by NACOBTA (U. Hdjavera, pers. comm.). Third, many (overseas) tourists book package tours when travelling through Namibia. Package tour providers, however, do not offer trips to the southern communal areas but usually stop in Keetmanshoop before going further to the Fish River Canyon, Ai-Ais or other more popular tourist attractions. In addition, the use of wildlife will also not provide high enough revenues to constitute an alternative landuse option to farming, even though revenues from wildlife utilisation could be increased if the conservancy engaged in trophy hunting, live sales or meat sales instead of only own consumption options (see Ashley et al. 1997 for numerical examples).

Moreover, even the most successful conservancies, which cover their costs and earn relative high revenues, generate benefits at a household level, which are too low and not sufficient to constitute an alternative to livestock farming or agriculture (Ashley & LaFranchi 1997, Bandyopadhyay et al. 2004). This, at least, is the case for the vast majority of members who are not employed by the conservancy and thus do not receive a monthly income. Currently, the !Khob!Naub conservancy has an annual expenditure of at least N$36,200 (which includes only the salaries for game guards and the coordinator as well as the allowances for committee members, paid by ICEMA) and annual revenues of N$1,600 originating from member fees plus earnings from occasional livestock sales. To state the obvious, the gap between expenditures and revenues is huge and will require an enormous effort if it is to be closed, not to mention the challenges of generating net revenues.

Given all these facts, we do not believe that conservancies in the south will constitute an alternative landuse option to farming. Nevertheless, conservancies constitute an additional landuse option as they generate material and non-material benefits on local and community level, which reduce vulnerability and complement local livelihoods. Material benefits comprise jobs, game donations, and meat distribution. Increased local empowerment and pride due to the reintroduction of rare species are important non-material benefits. Another potential merit of a conservancy is the provision of an institutional platform, which may serve as a starting point for further collective action. In addition to the economic benefits, the conservancy establishment in the !Khob!Naub area has led to an increase in wildlife populations and diversity as well as an increase in environmental awareness among local resource users.

Ecological impacts of communal farming in southern Namibia: an interdisciplinary case study

[N. Dreber & T. Falk]

Land degradation is a widespread problem in Namibia, particularly in communal areas affected by high population and livestock densities, and non-adaptive land management (Klintenberg & Seely 2004). This issue has been investigated at the adjacent BIOTA Observatories of Gellap Ost and Nabaos in the Keetmanshoop region in the context of an interdisciplinary research effort. There is a marked fence-line contrast between the state research farm Gellap Ost and the communal area of Nabaos which forms part of Namaland (Photos 4 & 5). Fence-line contrasts create a visual impression of the differences in rangeland condition and allow for an analysis of long-term consequences of different landuse practices on the biotic and abiotic environment (Zimmermann 2009). This, in turn, provides important information about ecosystem dynamics, resistance, and resilience (Todd & Hoffman 2009).

Previous socio-economic studies have examined different resource use strategies of farmers in the study area, and have investigated which factors at different socio-political scales influence their landuse strategies (e.g. Falk 2008). Due to the absence of economic incentives for profit maximisation, rangelands of Gellap Ost are stocked at lower rates than those recommended by the Ministry of Agriculture, Water and Forestry. This fact together with a sophisticated management system of rotational grazing and rangeland monitoring has contributed to a situation where BIOTA researchers could not observe any signs of rangeland degradation in Gellap Ost. These rangelands can be regarded as a reference for intact ecosystems in terms of biodiversity and ecosystem functioning. In contrast, on the communal rangeland of the Nabaos unit, strong competition over resources and inappropriate governance structures has resulted in poor range management and high stocking rates (Falk 2008). The governance system of the area is weak as neither traditional nor statutory organisations are present at the local level. Newly established water point committees could potentially fill the institutional gap at the local level and could play an important role in overall natural resource management (Falk et al. 2009). To date they are, however, overburdened with this task as the community cohesion is very low. The poor resource management is particularly expressed in a reduced availability of natural resources and ecosystem functioning. At least since the late 1970s when land tenure changed from commercial to communal (Kuiper & Meadows 2002), severe grazing mainly by goats and free-roaming donkeys, combined with a high variability in rainfall, has contributed to the current degraded state of Nabaos' rangelands.

In this chapter we summarise the socio-economic, botanical, zoological, mycological, and pedological studies which together demonstrate a cause-and-effect chain. Various ecological studies have analysed the long-term impact of severe overgrazing on the formerly grassy shrublands, now degraded open shrublands, using the fence-line contrast approach. The interdisciplinary studies conducted at both BIOTA Observatories provide a broad insight on how long-term, unsustainable landuse is able to transform the physical environment, affect different groups of organisms, and limit the natural regeneration capacity of the rangeland towards healthy ecological states.

Kuiper & Meadows (2002) compared aerial photographs from 1970 and 1998 and detected a 5% increase in bare ground in the whole Nabaos communal area, while cover has remained relatively constant in the rangelands of Gellap Ost. An increase in bare ground was also observed at the scale of the BIOTA Observatory when contrasting Gellap Ost and Nabaos. The reduced vegetation cover on Nabaos is mainly due to the loss of perennial grasses such as *Stipagrostis uniplumis* (Blinkhaarboesmangras) and *S. hochstetteriana* (Gemsbokstertgras), which dominate the inter-shrub matrix on Gellap Ost and reach the highest cover values of all species present at this site (Wolkenhauer 2003). On the communal site, continuous high grazing pressure profoundly reduced the abundance of perennial grasses and favoured the abundance of generalists such as the annual prostrate forbs *Indigastrum argyroides* and *Trianthema parvifolia* (Rooi-rankvygie), and the annual grasses *Schmidtia kalahariensis* (Kalaharisuurgras) and *Aristida adscensionis* (Eenjarige Steekgras) in the herbaceous layer. Both grasses can be regarded as indicators of degradation if occurring in such dense stands (Müller 2007). A comparison of grass species occurring on the Gellap Ost and Nabaos Observatory in March 2006 revealed that Gellap Ost is more diverse (22 species versus 14 on Nabaos), and most of them are perennial species with high nutritional value (sensu Müller 2007). In contrast, climax grasses and even sub-climax grasses with some grazing value are seldom present on Nabaos (N. Dreber, unpublished data). In addition to the qualitative and quantitative differences in grass species composition, the presence of arbuscular mycorrhizae fungi (AM-fungi) in grass species was found to be significantly reduced on Nabaos compared to Gellap Ost, although spore communities and spore numbers were similar among the sites (Uhlmann et al. 2006). These symbionts supply the host with water and nutrients receiving organic carbon in return, thereby increasing plant growth. There is evidence for a reduction of mycorrhization of grasses by AM-fungi due to grazing in semiarid grasslands, which may not only affect plant nutrition, but also soil structure and soil stability (Bethlenfalvay et al. 1985). The shift in availability and quality of fodder highlight the relatively poor condition of the ecosystem and point to the limited possibility of farming with grazers such as sheep, whose diet largely consists of grasses and forbs. The woody vegetation on Nabaos provides, however, some available fodder for goats throughout the year with common shrubs such as *Acacia nebrownii* (Slapdoring), *Calicorema capitata*, *Monechma genistifolium* (Perdebos), *Rhigozum trichotomum* (Driedoring) and *Tetragonia schenckii* (Kooibos) being heavily browsed (N. Dreber, pers. observation). Nevertheless, the compositional shifts towards the dominance of annual species leads to higher inter-annual as well as seasonal variations in plant cover, but also in phytodiversity and biomass production. This makes Nabaos farmers more vulnerable to livestock losses even in times of moderate rainfall.

In the dry season and during drought periods only the woody vegetation remains on Nabaos, while on Gellap Ost the prominent perennial grasses still provide much standing biomass (Photos 4 & 5). These grasses are effective in stabilising the upper layer of soil in the inter-shrub matrix, thus preventing soil erosion by wind and water. Conversely, soils on Nabaos are prone to erosion due to the lower efficiency of its annual vegetation to stabilise the soil and an increased topsoil disturbance caused by livestock trampling (Petersen 2008). Moreover, loamy layers with small, vesicular inclusions in the topsoil, which reduce water infiltration and increase runoff, are more strongly developed on Nabaos than on Gellap Ost. Their development is likely to be favoured by higher topsoil temperatures and water evaporation rates resulting from reduced plant cover (Petersen 2008). Water is the limiting factor for plant growth and vegetation recovery, and therefore the inability of degraded rangeland soils to retain water limits its regeneration capacity. On Gellap Ost, a small scale mosaic of vegetated patches on sandier soils and bare patches on loamier soils maintains source-sink processes, such as the redistribution and entrapment of nutrients, organic material and water (Petersen 2008). Local resource concentrations favour plant establishment and biomass production, and increase water infiltrability at the vegetated patch, which in turn maintains the mosaic of vegetation patches and bare ground (Rietkerk et al. 2002). On Nabaos, however, respective ecosystem functioning at the patch scale is largely altered, and thus the rangeland is dysfunctional to some degree. There are strong ecohydrological interactions in arid environments, with vegetation patches obstructing runoff and storing significantly more water than bare patches (Ludwig et al. 2005). Popp et al. (2009) developed a vegetation model for ecohydrological feedback mechanisms parameterised for the Gellap Ost and Nabaos sites. It incorporates structural elements of the vegetation, spatio-temporal water availability through precipitation and redistribution processes, topography and disturbance (grazing) parameters. The simulation results revealed that overgrazing has a profound effect on hydrological processes and associated vegetation productivity. The loss in vegetation cover increases run-off and evaporation from the soil, and thus limits the landscape's ability to retain and conserve water, which leads to an additional reduction in forage production (Popp et al. 2009). The interrelated changes in plant species composition, vegetation cover, soil properties, and water balance of the ecosystem as a consequence of high livestock pressure render the degraded communal rangelands vulnerable to environmental threats such as droughts, but also heavy rainfall events.

The grazing regime on Nabaos has transformed the structure and composition of the vegetation. It has also transformed the physical environment with knock-on effects for the fauna of the region. As shown for small mammal communities, species richness, abundance, diversity and settlement of rodents is lower on the overgrazed Nabaos Observatory (Hoffmann & Zeller 2005). The most frequent species at Gellap Ost, *Gerbilliscus leucogaster* (Bushveld Gerbil), prefers a savanna-like environment, and did not occur on Nabaos. In contrast, *Gerbillurus vallinus* (Brush-tailed Gerbil), a desert inhabitant, was the dominant species on Nabaos, while it was only subdominant at Gellap Ost. Obviously, this xeric-adapted species has found a more suitable habitat in the transformed, more open rangeland of Nabaos than in the grassy shrubland of Gellap Ost (Hoffmann & Zeller 2005). The authors conclude that the changes in small mammal community were caused by the disrupted habitat structure, reduced shelter and higher predation risks resulting from the reduced vegetation cover, as well as by the reduction in food supply as a result of the smaller population of arthropods on Nabaos. Indeed, arthropod surveys conducted at the Observatories (e.g. Vohland et al. 2005) revealed for example a reduction of termite numbers on Nabaos, which might be related to the low grass biomass. As termites are also important in the diet of small mammals, their reduction might have an impact on these animals. Further, the abundance and diversity of beetles (Coleoptera) were also reduced on Nabaos. Overall, this leads to a reduction of ecosystem functions provided by arthropods such as infiltration and water holding capacity of the soil, pedoturbation, and turn-over in nutrients (Vohland et al. 2005).

This research demonstrates the ecological consequences of inappropriate land management. The interactions between continuous overstocking, reduced vegetation cover, soil deterioration, and shifts in biodiversity result in a loss of landscape functional integrity (sensu Ludwig et al. 2004). The path for the improvement of rangeland condition depends on the rehabilitation potential of the ecosystem and is specific to the given socio-economic context. An important aspect in rangeland rehabilitation is the regeneration capacity of vegetation towards a more desirable state. In the case of Nabaos, a recovery of target plants such as perennial grasses would result in a change in vegetation structure and

Photos 4 and 5: Fence-line contrast between Gellap Ost (left of fence) and Nabaos in the wet season (left; 15.04.2008) and dry season (right; 23.01.2008). Photos: N. Dreber.

improve ecosystem functioning by contributing to the prevention of erosion, enhancing the water balance, and providing fodder for insects, rodents, and livestock. However, the recovery of desirable vegetation depends largely on intact soil seed banks and establishment conditions. The analysis of soil seed banks is a constructive tool to assess the condition and restoration potential of a site (Jones & Esler 2004). It can yield information on the current seed reserves and allows one to predict the overall composition of post-disturbance vegetation (van der Valk & Pederson 1989). Further, if the aim is to improve site conditions or re-establish a target plant community, the examination of soil seed bank formation prior to the initiation of any management strategy is important, as the knowledge derived from such an analysis can be used to structure and accelerate the restoration process (Chambers & MacMahon 1994). A respective approach was initiated in 2006 with a pilot study assessing species richness and species composition of the seed bank, and seed densities on Nabaos and Gellap Ost (Dreber 2010). Based on this study, a detailed seed bank analysis was conducted in 2007 and 2008 (N. Dreber, University of Hamburg, unpublished data). Results revealed that the soil seed bank on Nabaos is altered and mirrors the species composition of the standing vegetation. Species common on Gellap Ost, which has been managed sustainably, are generally absent. In addition, a shift in the abundance of plant functional groups towards the dominance of grazing resistant prostrate annuals was also detected. In particular, seeds of perennial grasses were significantly reduced. While the seed bank on Gellap Ost consisted of 11% of perennial grasses (*Stipagrostis uniplumis* and *S. hochstetteriana*), these made up less than 0.2% of germinated seeds from the seed bank of Nabaos. This points to an inability of perennial grasses to establish and replenish the seed bank, which may indicate a low availability of safe sites for seed capture and/or high grazing pressure on seed-bearing plants (Kinloch & Friedel 2005). An analysis of similarity revealed that the species composition of the seed bank at Nabaos was significantly different from that of Gellap Ost. Even safe sites such as under shrubs, which are effective in trapping and accumulating dispersing seeds, provided no desirable seed material, although seed bank richness and seed densities were highest under shrub canopies (mean of 3460–5150 seeds m^{-2}). This also indicates that the seed input via seed rain from the adjacent Gellap Ost rangeland is limited. Accordingly, the potential of degraded vegetation to recover and to support species which are common to rangelands which have been managed sustainably is low, particularly if recovery is not supported by active intervention.

The contrast between Gellap Ost and Nabaos documents the impact of land degradation both above and below ground. The interdisciplinary studies have identified several indicators, which can be used to assess the degree of transformation in a Nama Karoo ecosystem. They also provide reference points for future assessments of rangeland condition and evaluations of restoration potentials. These indicators can be used to support the introduction of either restoration methods in degraded habitats or preventive methods for conserving biodiversity. In the case of Nabaos, results indicate a profound regime shift and loss of ecosystem functioning with the natural regeneration of habitats unlikely to occur even under an adaptive management approach. Recovery processes of degraded arid rangelands are slow, and the time-span for improvement might take 60 years or more (Wiegand & Milton 1996). As no desirable seed material is available at the degraded site, post-disturbance vegetation is likely to be no different from the present vegetation, at least in a time span relevant to present farmers. Therefore, in order to improve site conditions active restoration, implemented in a long-term management framework, is indispensable. In practice, effective ways to rehabilitate the rangeland may consist of the seeding of target species, creating refuges for vegetation regeneration and adopting appropriate grazing management systems including herding and resting periods. A rangeland rehabilitation program can only be developed together with all involved stakeholders. Landusers will accept alternative practices only if they recognise that new approaches affect their livelihoods in a positive way. One focus could therefore be to enhance the awareness of farmers, government officials, traditional authorities, and policy makers on the linkages between vegetation dynamics, soil condition, ecosystem water balance, biodiversity, natural resource productivity and livelihoods. It is of utmost importance to develop innovative approaches in order to improve existing management instruments and governance structures targeted at alleviating poverty through biodiversity conservation. Therefore, in order to avoid continuing resource degradation, institution-building at the local level is indispensable.

3.5 Rangeland—landuse interactions and suggestions for the management of pastoral systems in the Namibian Nama Karoo

[S. Domptail]

Background

A major insight delivered by the interdisciplinary research reported on here is the multi-faceted diversity, which characterises the Namibian Nama Karoo. The three sections of this chapter illustrate this diversity of ecological and institutional settings thanks to the presentation of different case studies. A major aspect is the diversity of tenure systems. The commercial and communal farming sectors comprise very different and somewhat opposed tenure systems, which occur side by side in the arid Nama Karoo. The Rehoboth farmlands, on the other hand, are characterised by a more diffuse system of small-scale private farms, where multiple-ownership introduces management problems typical for collectively-managed natural resources. While these differences do not make the comparison of case studies easy, they create a more complex and complete picture of the problems and drivers of landuse, and of the degradation patterns, which occur in all social-ecological systems of the Namibian Nama Karoo. Importantly, each tenure system appears to have its pitfalls and no system is a panacea for sustainable rangeland management. Solutions for sustainable management will be specific to each social-ecological system (Anderies et al. 2004, Ostrom 2007) because the farming systems considered are tightly coupled to the natural rangelands and local ecological and economic dynamics (Campbell et al. 2006). For instance, diversity of rangeland resources is a key asset specific to the commercial area around Keetmanshoop. In addition, the relatively close proximity to major urban centres (such as Keetmanshoop and Windhoek), which characterises all three study sites, distinguishes them from more remote zones with regard to the existence of alternative income sources. Nevertheless, some insights were gained into the functioning of the main socio-ecological systems associated with rangelands of the Namibian Nama Karoo and are presented in the following paragraphs.

Ecological drivers of rangeland dynamics

It is well-known that erratic and low rainfall drives vegetation dynamics. This in turn poses a major challenge for pastoral activity, which focuses on coping with the variation in biomass produced by natural rangelands. Research within the BIOTA project (Herpel 2008, Petersen 2008, Popp 2007, N. Dreber, unpublished data) has shown that hydrology, soils and soil seed banks are key elements of those dynamics at both small and larger levels of scale. An important property of the ecological dynamics of the system is its non-linearity. Thus when land deterioration has become established it may be very difficult to reverse. It is important therefore to avoid the risks associated with degradation by paying attention to how landuse impacts on key ecosystem processes.

Impact of landuse on rangelands

With regard to the conservation of healthy rangelands, we found that the use of Karakul sheep for the production of skins as the main (but not only) income-securing breed seemed compatible with rangeland conservation objectives. However, mixed herds appeared important in enabling the practice of both breeding and speculation side by side in non-mobile systems (i.e. when land resources are fixed and limited) and where rangeland resources allow it. Indeed, low breeding levels were found to be conducive to rangeland conservation because they enhance the farming system's flexibility with regard to drought. Resting is another key farming practice for conservation and was found to be most effective if practiced extensively in wet years. Although farmers' ecological and botanical knowledge may play an important role in their management strategies, botanical expertise was not found to correlate with a better ecological state of the rangeland on farms in the Rehoboth area. Other factors probably play a more important role. As for the main drivers of degradation, high past and present stocking rates summed to long term overgrazing and were found to have transformed ecosystems substantially at both the biotic and the abiotic levels. Impacts included increased rate of soil erosion, changes in habitat hydrology, shifts in plant species composition, both above ground and below ground, changes in small mammal and beetle communities. Finally, in the region of Rehoboth, small farm sizes and multiple farm ownership have both been found to reduce perennial grass cover and lead to degradation.

Drivers of landuse strategies

Managers of small commercial farms in the area of Keetmanshoop tend to emphasise the avoidance of overgrazing risks during drought by reducing herd size but have rather low variations in their herd size. While farm size is indeed a constraint, the real driver behind overgrazing is the understandable need that farmers have to generate an income from the land. In all systems, the combination of scarce land resources and of high income needs, often as a result of large household size, the purchase of land or the necessity to accommodate several families, was found to influence the specific strategy used on a farm. Ultimately, the limited access to resources affects rangeland condition, as well as the abundance of grasses and other resources such as fire wood-providing trees. Malfunctioning or absent formal and informal institutions for the regulation of access to resources, as well as designing, monitoring and enforcement of rules to govern these collectively have exacerbated the problem. In some communal areas, uncontrolled in-migration and the absence of spatial delimitation of resources or of exclusive property rights jeopardises efforts to implement grazing rules and to maintain infrastructure. Subsidies were granted to both communal and commercial farmers in the context of the drought relief policy and other programs until independence in 1992. However, these subsidies have maintained high numbers of livestock on communal areas during and immediately after droughts, thus potentially having a strong impact on rangeland health. In Rehoboth, they have also supported the development of farm infrastructure, thus artificially boosting the viability of small farms and favoured the establishment of multiple farm ownership. An important major driver for high stocking rates especially in the arid Nama Karoo communal lands, far from the economic dynamism generated by the capital Windhoek, is widespread poverty and unemployment leading people to search for opportunities to access to and generate income from the communal lands. Within the communal areas, livelihoods are so constrained that marginalised farmers are prevented from reducing their stock even in times of drought. Until recently, prices have also strongly affected landuse strategies, especially the herd composition of commercial ranches by favouring meat production. Yet, following the increase in the price of Karakul skins as well as the constraints linked to the implementation of the Small Stock Marketing Scheme, which virtually closed the South African market for live sheep, interest in Karakul is being revitalised. Finally, farmer-related drivers were also identified. These included farmers' interest in conservation per se and whether farmers are full-time or part-time farmers. While it may be argued that the pressure on the rangeland is higher when the household depends only on income from farming, we found that farmers with a several sources of income also increase the risk that their rangelands will become degraded. In commercial systems, part-time farmers benefiting from additional income adopted more opportunistic strategies and reacted to strong rainfall by purchasing much stock, thus creating the risk of de-coupling the herd and the ecology of their rangelands. In the communal systems, more time was spent on herding the flock and faster rotations were used to manage the grazing lands by full-time farmers. This suggests that due to the lack of an available labour force, part-time farmers are less likely to implement sound rotational grazing practices.

Towards solutions

Following from these insights, key elements of potential solutions to counteract the degenerative trend in the farming systems studied are highlighted. First, in the context of Namibia's land reform and land redistribution program, particular attention should be given simultaneously to (1) the access of individual farmers to key resources, (2) the size of the farm units in order to ensure the viability of farms in the long term and (3) the type of farm structure and ownership. With this last point, we highlight the potential role of joint farming at a scale, which is ecologically and economically sound. Furthermore, innovative structures with well-defined property rights must also be sought and new forms of cooperatives or conservancies are also needed. Second, many farming practices may be improved. For instance, manure in communal areas may be used as fertiliser and alternative energy sources such as solar ovens may alleviate the pressure on wood resources. The keeping of mixed herds and the combination of breeding high quality sheep and less high quality sheep for speculation purposes should be supported by the creation and maintenance of diversified markets for the diverse products rather than solely focussing on high quality products. Our analysis suggests that practices may be influenced by some well-targeted policy measures such as the provision of financial incentives for farms on which effective and measured rangeland conservation is achieved. Finally, the development of alternative or additional income sources is important in communal areas because recovery processes of degraded rangelands are slow and time-spans needed for improvement might last up to several decades. The rehabilitation of severely degraded rangelands will require the design and implementation of long term management frameworks together with a significant investment in active restoration efforts. Additional effort should also be allocated to the alleviation of poverty through the development of other economic activities and to the prevention of further degradation of the region's rangeland resources. Here local institutions and cooperation among farmers will play a key role and their development should be fostered. This will foster the development of rules perceived as fair and agreed upon by those concerned, rather than dictated in a top-down manner. Conservancies, while providing a context for the development of cooperative behaviour within the community do not seem likely to achieve an improvement in the ecological state of the communal lands as they do not include long term rangeland management plans. Conservancies nevertheless constitute a sound approach to reduce vulnerability and to provide additional income sources, even if the benefits generated and perceived by individual members of the community are rather low.

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References

Anderies, J.M., Janssen, M., Ostrom, E. (2004): A framework to anaylze the robustness of social-ecological systems from an institutional perspective. – Ecology and Society **9**(1): 18. http://www.ecologyandsociety.org/vol9/iss1/art18/.

Ashley, C. (1997): Summary report from fieldwork at Grootberg and Bergsig. – Windhoek: WILD Development Phase; Directorate of Environmental Affairs, Ministry of Environment and Tourism.

Ashley, C., LaFranchi, C. (1997): Livelihood strategies of rural households in Caprivi: implications for conservancies and natural resource management. – Research Discussion Paper No. 20. Windhoek: Directorate of Environmental Affairs, Ministry of Environment and Tourism.

Ashley, C., Barnes, J., Brown, C., Jones, B. (1997): Using resource economics for natural resource management. Namibia's experience. – Research Discussion Paper No. 16. Windhoek: Directorate of Environmental Affairs, Ministry of Environment and Tourism.

Bandyophadyay, S., Shyamsundar, P., Wang, L., Humavindu, M. (2004): Do households gain from community-based natural resource management? An evaluation of community conservancies in Namibia. – Research Discussion Paper No. 68. Windhoek: Directorate of Environmental Affairs, Ministry of Environment and Tourism.

Bandyopadhyay, S., Guzman, J.C., Lendelvo, S. (2008): Communal conservancies and household welfare in Namibia. – Washington D.C.: The World Bank.

Barnes, J.I., MacGregor, J., Weaver, C. (2002): Economic efficiency and incentives for change within Namibia's community wildlife use initiatives. – World Development **30**: 667–681.

Bausch, J., Domptail, S., Nuppenau, E. (2009): A report on the preferences for livelihood strategies of the communal farmers in Namaland, Namibia. – Giessen: University of Giessen.

Bethlenfalvay, G.J., Evans, R.A., Lesperance, A.L. (1985): Mycorrhizal colonisation of crested wheatgrass as influenced by grazing. – Agronomy Journal **77**: 233–236.

Britz, R.G., Lang, H., Limpricht, C. (1999): A concise history of the Rehoboth Basters until 1990. Appendix: the laws of the Rehoboth Basters. – Windhoek & Göttingen: Klaus Hess.

Bulte, E.H., Lipper, L., Stringer, R., Zilberman, D. (2008): Payments for ecosystem services and poverty reduction: conpcets, issues, and empirical perspectives. – Environment and Development Economics **13**: 245–254.

Buß, H.J. (2006): Land use options of Namibian farms. Optimal management strategies proposed by bioeconomic models. – Agrarökonomische Studien **26**. Kiel: Wissenschaftsverlag Vauk.

Byers, B.A. (1997): Environmental threats and opportunities in Namibia: a comprehensive assessment. – Research Discussion Paper No. 21. Windhoek: Directorate of Environmental Affairs, Ministry of Environment and Tourism.

Campbell, B.M., Gordon, I.J., Luckert, M.K., Petheram, L., Vetter, S. (2006): In search of optimal stocking regimes in semi-arid grazing lands: one size does not fit all. – Ecological Economics **60**: 75-85.

Chambers, J.C., MacMahon, A.J. (1994): A day in the life of a seed: movements and fates of seeds and their implications for natural and managed systems. – Annual Review of Ecology and Systematics **25**: 263-292.

Corbett, A., Jones, B.T.B. (2000): The legal aspects of governance in CBNRM in Namibia. – Research Discussion Paper No. 41. Windhoek: Directorate of Environmental Affairs, Ministry of Environment and Tourism.

Domptail, S.E., Popp, A., Nuppenau, E.-A. (2009): A trade-off analysis between rangeland health and income generation in southern Namibia. – In: Kontoleon, A., Pascual, U., Smale, M. (eds.): Agrobiodiversity, conservation and economic development: 204–232. Abingdon: Routledge.

Domptail, S., Nuppenau, E.-A., Popp, A. (in press): Land tax: towards a multifunctional Institutional tool for land reform and rangeland conservation. – International Journal for Environmental Policy and Decision Making.

Dreber, N. (2010): How best to quantify soil seed banks in arid rangelands of the Nama Karoo? – Environmental Monitoring and Assessment. DOI: 10.1007/s10661-010-1425-4.

Ekongo, J. (2005): Goat exports to SA on the rise. – New Era, September 7, 2005. http://www.newera.com.na/article.php?db=oldarchive&articleid=8726 [acc. 07.09.2005].

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.

Falk, T., Bock, B., Kirk, M. (2009): Polycentrism and poverty: experiences of rural water supply reform in Namibia. – Water Alternatives **2**: 115–137.

FAO (1998): World reference base for soil resources. – World Soil Resources Reports **84**. Rome: FAO.

Gibreel, T. (2009): Impact of agricultural policy on resource allocation in the gum belt of Sudan: a farm household modeling approach. – Farming & Rural Systems Economics **105**. Weikersheim: Margraf.

Giess, W. (1971): A preliminary vegetation map of South West Africa. – Dinteria **4**: 1–114.

Grotehusmann, L. (2006): Analyse der Böden und ihrer Eigenschaften in Bezug auf Fernerkundungsdaten im südlichen Namibia (Raum Keetmanshoop). – Diplom thesis in Biology. Hamburg: University of Hamburg.

Grotehusmann, L., Gröngröft, A, Petersen, A. (2006): Investigation on soil properties in the Keetmanshoop district as a tool for soil mapping with LANDSAT remote sensing data - short report. – Hamburg: University of Hamburg.

GTZ (2006): Economics of landuse. Financial and economic analysis of land-based development schemes in Namibia. – Windhoek: Deutsche Gesellschaft für Technische Zusammenarbeit; Natural resource management and rural development.

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

Heyns, P., Montgomery, S., Pallet, J., Seely, M. (1998): Namibia's water: a decision makers' guide. – Windhoek: Desert Foundation of Namibia and the Directorate of Water Affairs.

Hoffmann, A., Zeller, U. (2005): Influence of variation in landuse intensity on species diversity and abundance of small mammals in the Nama Karoo, Namibia. – Belgian Journal of Zoology **135**: 91–96.

Hunter, J. (2004): Who should own the land? An introduction. – In: Hunter, J. (ed.): Who should own the land? Analyses and views on land reform and the land question in Namibia and Southern Africa: 1–7. Windhoek: Namibia Institute for Democracy (NID).

Jones, B., Murphree, M. (2001): The evolution of policy on community conservation in Namibia and Zimbabwe. – In: Hulme, D., Murphree, M. (eds.): African wildlife and livelihoods: the promise and performance of community conservation: 37–58. Oxford: James Curry.

Jones, F.E., Esler, K.J. (2004): Relationship between soil-stored seed banks and degradation in eastern Nama Karoo rangelands (South Africa). – Biodiversity and Conservation **13**: 2027–2053.

Kahuika, S., Tutalife, C., Motinga, D. (2006): Adding value with mutton: is pricing everything? – IPPR Briefing Paper No. 40. Windhoek: Institut for Public Policy Research.

Karamata, C. (2006): Farm workers in Namibia. Living and working conditions. – Windhoek: LaRRI.

Kinloch, J.E., Friedel, M.H. (2005): Soil seed reserves in arid grazing lands of central Australia. Part 2: Availability of 'safe sites'. – Journal of Arid Environments **60**: 163–185.

Klintenberg, P., Seely, M. (2004): Land degradation monitoring in Namibia: a first approximation. – Environmental Monitoring and Assessment **99**: 5–21.

Klocke-Daffa S. (2001): „Wenn du hast, mußt du geben“. Soziale Sicherheit im Ritus und im Alltag bei den Nama von Berseba/ Namibia. – Studien zur Sozialen und Rituellen Morphologie **3**. Münster: Lit.

Kuiper, S.M., Meadows, M.E. (2002): Sustainability of livestock farming in the communal lands of southern Namibia. – Land Degradation and Development **13**: 1–15.

Lang, H. (1998): The population development of the Rehoboth Basters. – Anthropos **93**: 381–391.

Lang, H. (1999): The transition from communal to private land ownership in Rehoboth, Namibia. – Zeitschrift für Ethnologie **124**: 319–333.

Lang, H. (2005): The farm system of the Rehoboth Basters (Namibia): the situation in 1999/2000. – Zeitschrift für Ethnologie **130**: 223–243.

Lang, H., Challenor, P., Killworth, P.D. (2004): A new addition to the family of space sampling methods. – Field Methods **16**: 55–69.

Limpricht, C., Lang, H. (2008): Farms and families: land tenure in Rehoboth. – In: Limpricht, C., Biesele, M. (eds.): Heritage and cultures in modern Namibia: in-depth views of the country. A TUCSIN-Festschrift: 141–154. Windhoek & Göttingen: Klaus Hess.

Ludwig, J.A., Tongway, D.J., Bastin, G.N., James, C.D. (2004): Monitoring ecological indicators of rangeland functional integrity and their relation to biodiversity at local to regional scales. – Austral Ecology **29**: 108–120.

Ludwig, J.A., Wilcox, B.P., Breshears, D.D., Tongway, D.J., Imeson, A.C. (2005): Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. – Ecology **86**: 288–297.

MAWF (2004): Coefficient of variation of total seasonal above ground biomass production – 1985/6–2002/3 growing seasons. – Windhoek: Ministry of Agriculture, Water, and Forestry.

MAWF (2005): Agro-ecological zones and biomass growth map. – Windhoek: Ministry of Agriculture, Water, and Forestry.

Meat Board of Namibia (2010a): Market statistics. – http://www.nammic.com.na/stats.php#prod [acc. 11.03.2010].

Meat Board of Namibia (2010b): Meat industry performance in 2007. – http://www.nammic.com.na/stats.php [acc. 11.03.2010].

Mendelsohn, J. (ed.) (2006): Farming systems in Namibia. – Windhoek: Research and Information Services of Namibia.

Müller, B., Linstaedter, A., Frank, K., Bollig, M., Wissel, C. (2007): Learning from local knowledge: modelling the pastoral-nomadic range management of the Himba, Namibia. – Ecological Applications **17**:1857–1875.

Müller, M.A.N. (2007): Grasses of Namibia. Revised edition by J. van Eck. – Windhoek: Ministry of Agriculture, Water and Forestry.

NACSO (2006): Namibia's communal conservancies. A review of progress and challenges. – Windhoek: Namibia Nature Foundation (NNF).

NACSO (2008): Namibia's communal conservancies. A review of progress and challenges – Windhoek: Namibia Nature Foundation (NNF).

Naumann, C. (2009): Weidemanagement und ethnobotanisches Wissen bei den Rehobother Bastern. – Master thesis in Social Anthropology. Hamburg: University of Hamburg.

Odendaal, W. (2006): The SADC land and agrarian reform: the case of Namibia. – NEPRU Working Paper **111**: 1–56.

Ostrom, E. (2007): A diagnostic approach for going beyond panaceas. – Proceedings of the National Academy of Sciences of the United States of America **104**: 15181–15187.

Palmer, A.R., Hoffman, T. (1997): Nama-karoo. – In: Cowling, R.M., Richardson, D.M., Pierce, S.M. (eds.): Vegetation of southern Africa: 167–186. Cambridge: Cambridge University Press.

Petersen, A. (2008): Pedodiversity of southern African drylands. – Hamburger Bodenkundliche Arbeiten **61**: 1–347.

Popp, A. (2007): An integrated modelling approach for sustainable management of semi-arid and arid rangelands. – PhD Thesis. Potsdam: University of Potsdam.

Popp, A., Blaum, N., Jeltsch, F. (2009): Ecohydrological feedback mechanisms in arid rangelands: Simulating the impacts of topography and landuse. – Basic and Applied Ecology **10**: 319–329.

Rietkerk, M., Boerlijst, M.C., Langevelde, F. van, HilleRisLambers, R., Koppel, J. van de, Kumar, L., Prins, H.H.T., Roos, A.M. de (2002): Self-organisation of vegetation in arid ecosystems. – The American Naturalist **160**: 524–530.

Republic of Namibia (1998): National Land Policy. – Windhoek: Ministry of Lands, Resettlement and Rehabilitation.

Republic of Namibia (2002): Communal Land Reform Act No. 5 of 2002. – Government Notice No. 137. Government Gazette of the Republic of Namibia No. 2787: 1–35.

Schönherr, S. (1989): Sektorstudie ländliche Regionalentwicklung. Wirtschaftliche Strategien, Potentiale und Förderungsmöglichkeiten in den kommunalen Gebieten. – Grundlagenstudie Namibia **5**. München: Ifo-Inst. für Wirtschaftsforschung.

Schuh, C., Conroy, C., Grimm, J., Humavindu, M., Kwala, C., Ströbel, H., Werner, W. (2006): Economics of landuse. Financial and economic analysis of land-based development schemes in Namibia. – Windhoek: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Natural Resource Management and Rural Development.

Schutz, W. (2009): Report on the small stock marketing scheme. – Windhoek: Meat Board Namibia.

Sweet, J. (1999): Livestock – coping with drought: Namibia – a case study. –Rome: FAO. http://www.odi.org.uk/networks/pdn/drought/sweet.pdf

Sweet, J., Burke, A. (2002): Namibia country pasture/forage resource profiles. –http://www.fao.org/ag/AGP/AGPC/doc/counprof/Namibia/namibia.htm#3.2%20Communal/traditional [acc. 01.02.2010].

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

Uhlmann, E., Görke, C., Petersen, A., Oberwinkler, F. (2006): Arbuscular mycorrhizae from arid parts of Namibia. – Journal of Arid Environments **64**: 221–237.

Valk, A.G. van der, Pederson, R.L. (1989): Seed banks and the management and restoration of natural vegetation. – In: Leck, M.A., Parker, V.T., Simpson, R.L. (eds.): Ecology of soil seed banks: 329–346. San Diego: Academic Press.

Vohland, K., Uhlig, M., Marais, E., Hoffmann, A., Zeller, U. (2005): Impact of different grazing systems on diversity, abundance and biomass of beetles (Coleoptera), a study from southern Namibia. – Mitteilungen des Museum für Naturkunde Berlin, Zoologische Reihe **81**: 131–143.

Vollan, B. (2009): Co-operation for common pool resources: an experimental perspective. – PhD thesis in Economics. Marburg: University of Marburg.

Weidlich, B. (2006): Full story: good prices for sheep at abattoirs, industry says. – The Namibian, 6 December 2006. http://www.namibian.com.na/index.php?id=28&tx_ttnews[tt_news]=22848&no_cache=1 [acc. 01.02.2010].

Werner, W., Kruger, B. (2007): Redistributive land reform and poverty reduction in Namibia. Draft. – Country paper. Livelihoods after land reform (LALR).

Westoby, M., Walker, B., Noy-Meir, I. (1989): Opportunistic management for rangelands not at equilibrium. – Journal of Range Management **42**: 266–274.

Wesuls, D., Lang, H. (2010): Perceptions and measurements: the assessment of pasture states in a semi-arid area of Namibia. – Human Ecology **38**: 305–312.

Wesuls, D., Naumann, C., Limpricht, C. (2009): Algemeene plante in die Rehoboth streek: veld gids vir plaasboere. Common plants in the Rehoboth area: a farmers field guide. – Hamburg & Windhoek: BIOTA Southern Africa.

Wiegand, T., Milton, S.J. (1996): Vegetation change in semiarid communities. Simulating probabilities and time scales. – Vegetatio **125**: 169–183.

Wolkenhauer, C. (2003): Vergleichende vegetationsökologische Untersuchungen auf den Farmgebieten Gellap-Ost (Rotationsweide) und Nabaos (kommunales Weideland) im südlichen Namibia. – Diplom thesis in Biology. Hamburg: University of Hamburg.

Zimmermann, I. (2009): Causes and consequences of fenceline contrasts in Namibian rangeland. – PhD thesis. Bloemfontein: University of the Free State.

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

Part IV

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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]

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).


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 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).

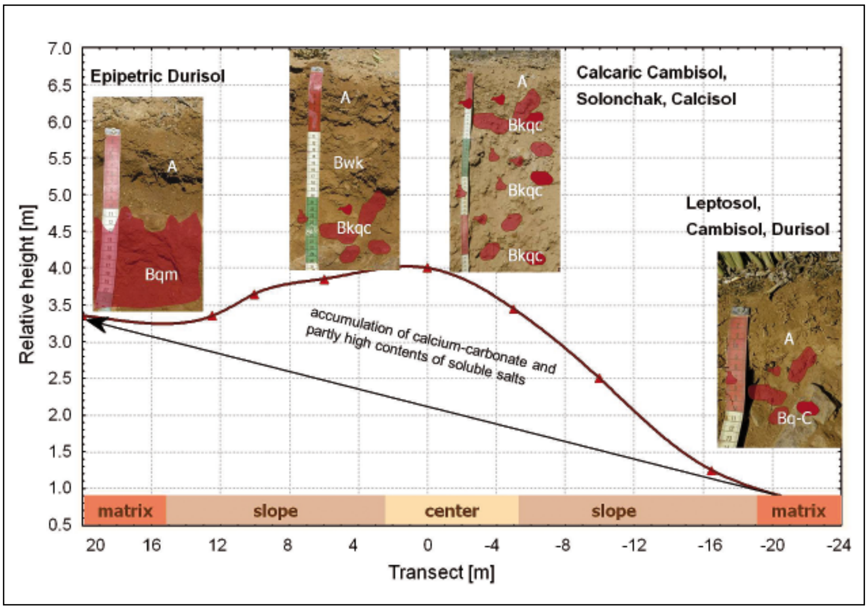


Fig. 1: Schematic representation of the heuweltjie transect in Soebatsfontein showing typical soil units and their position. Durinodes and Duripans are highlighted in reddish colour. (A/B/C represents the main soil horizons, suffix k = accumulation of calcium-carbonates; qc = accumulation of silica concretions;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

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 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 cm² 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 m²) to micro-scale (< 1 m²). 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 m²) 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 cm²) and plot (1000 m²) 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 m²) 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 m²) 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).

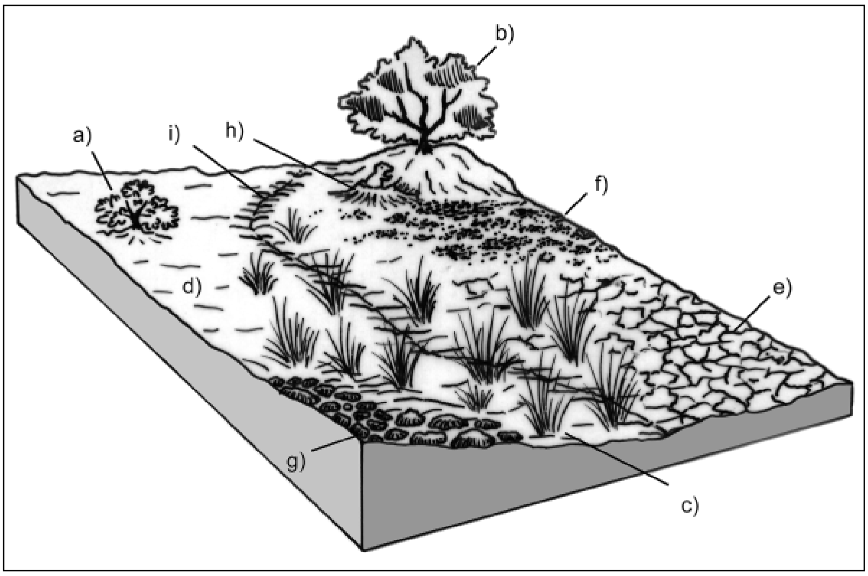


Fig. 2: Diagrammatic representation of micro-features in an idealised dryland landscape. a) dwarf-shrub, b) larger shrubs, c) tussock grasses, d) open soil patch, e) mineral soil crust, f) biological soil crust, g) pebble covered areas, h) disturbance spot caused by digging animals, and i) small depressions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

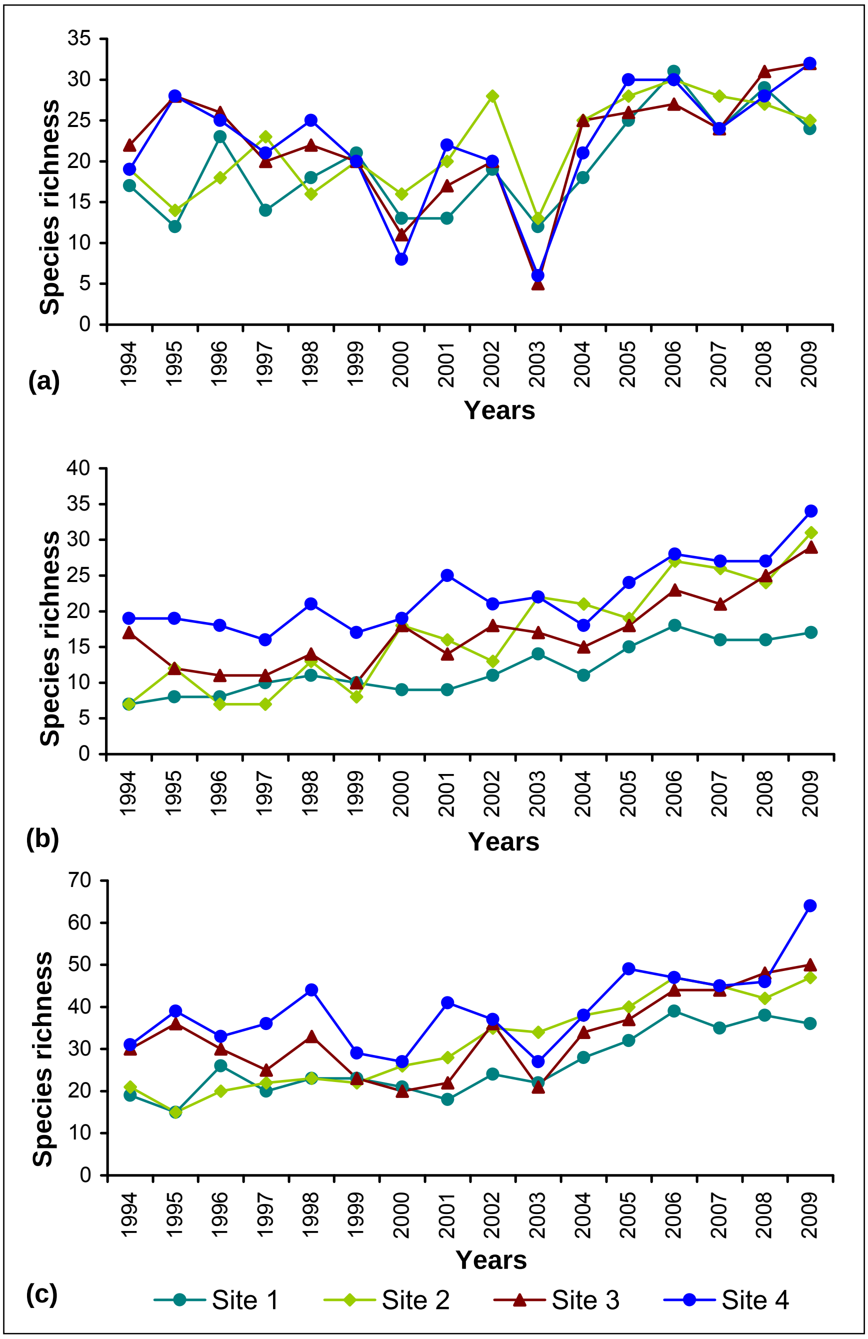


Fig. 3: Changes in species richness of (a) annual species (b) perennial species and (c) total species at the four monitoring sites from 1994 to 2009.

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 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

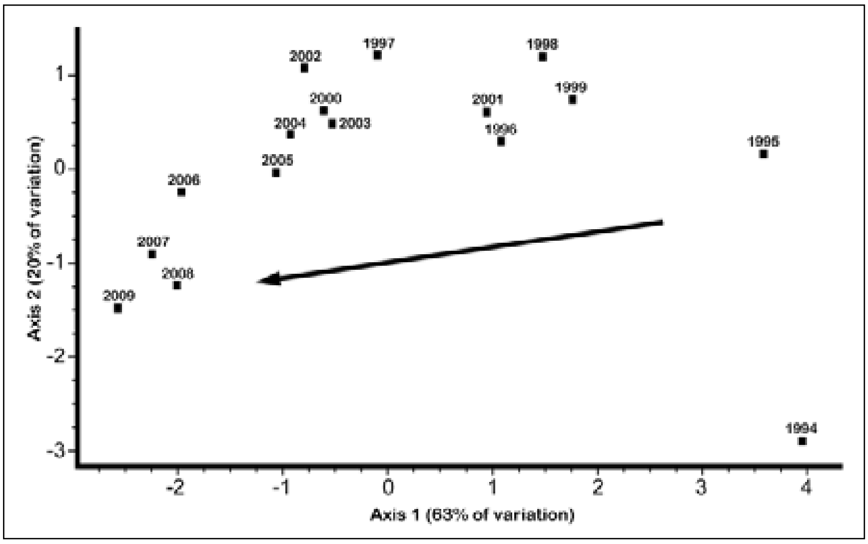


Fig. 4: Directional changes in species composition at monitoring site 1 from 1994 to 2009.

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?

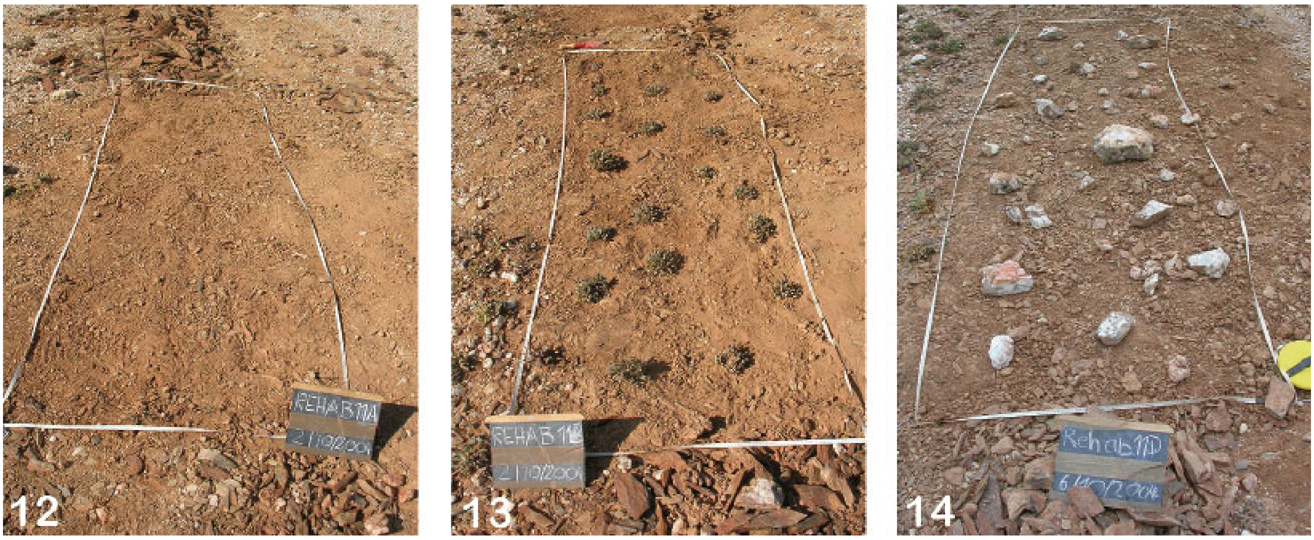
Rangeland degradation in the Succulent Karoo

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	—	—

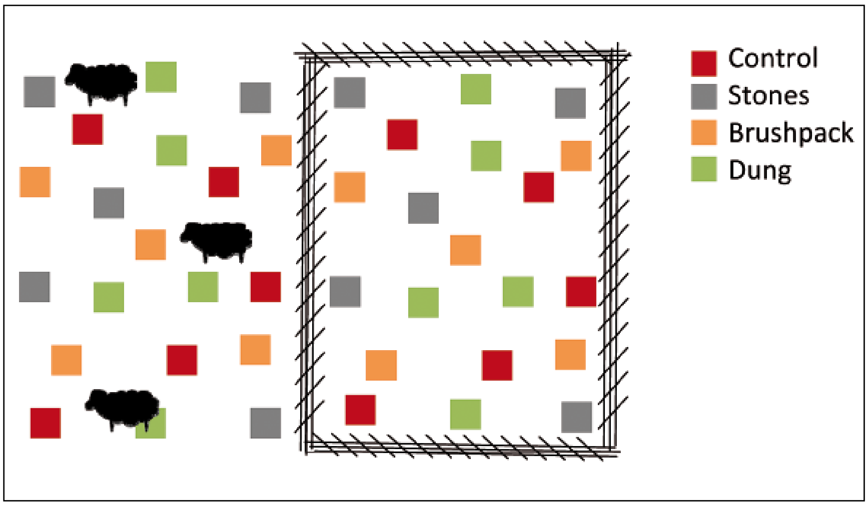


Fig. 5: Split-plot design at Soebatsfontein. The experimental site is divided into two plots of which one is fenced, while the other is grazed by livestock. Each plot contains subplots within which the active treatments were randomly allocated (modified from Meyer 2009).

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.

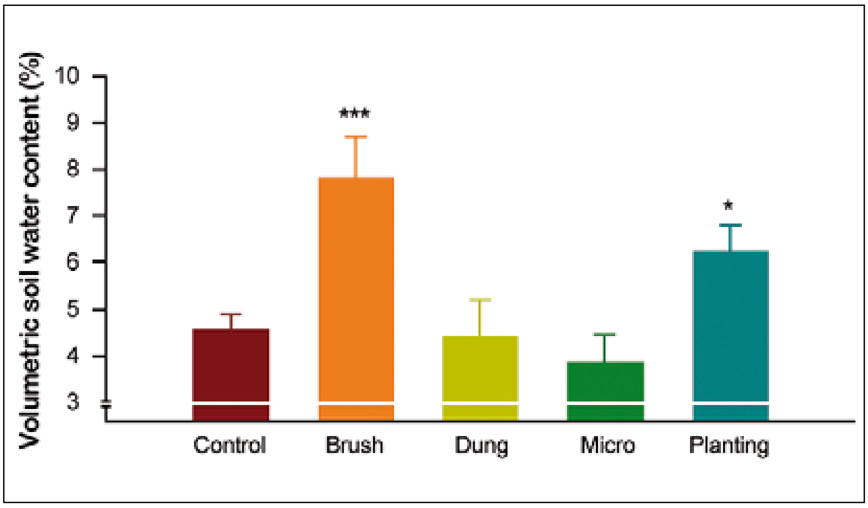


Fig. 6: Mean (+1 SE) volumetric soil water content after a rainfall event of 5.2 mm at Eksteenfontein. Asterisks indicate significant differences from the control derived from pairwise a priori comparisons following the analyses using linear models (*$p < 0.05$; ***$p < 0.001$), $N = 10$; Micro = microcatchment,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

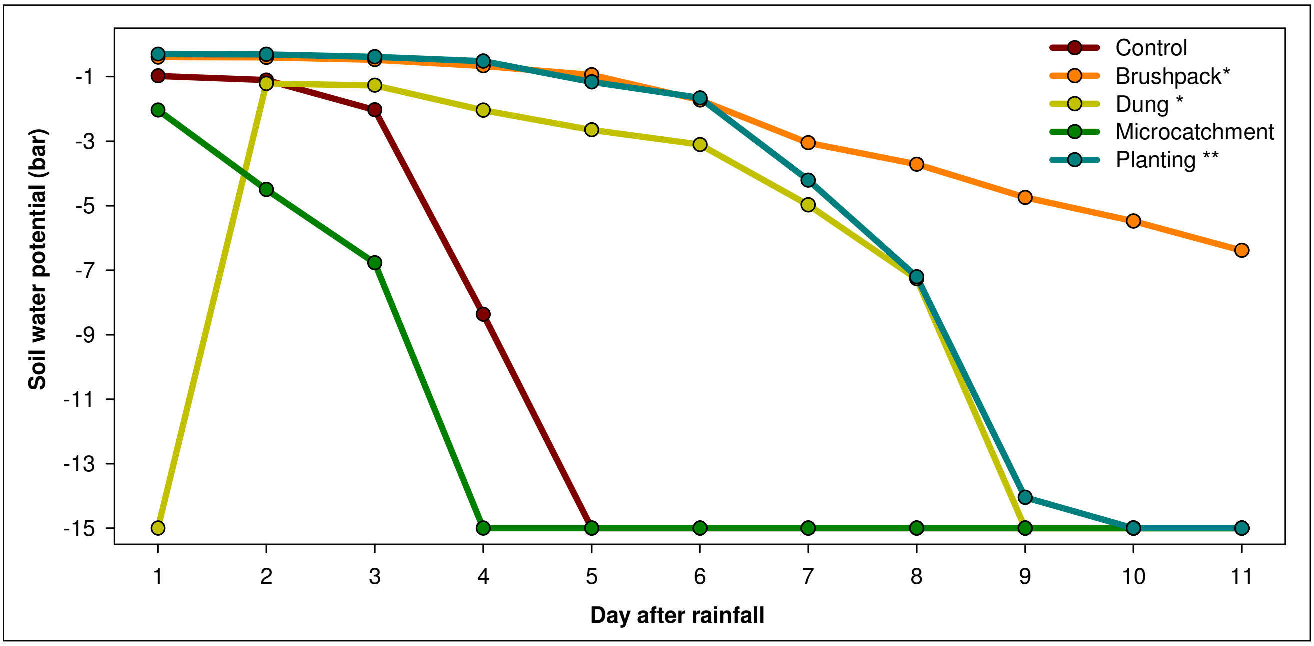


Fig. 7: Soil water depletion curves after a rainfall event of 5.2 mm. Data are medians of water potential over 11 days at 5 cm soil depth from gypsum block sensors (GB-1, Delmhorst Instrument Co.). Asterisks in the legend indicate significant differences from the control of treatment by time interaction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

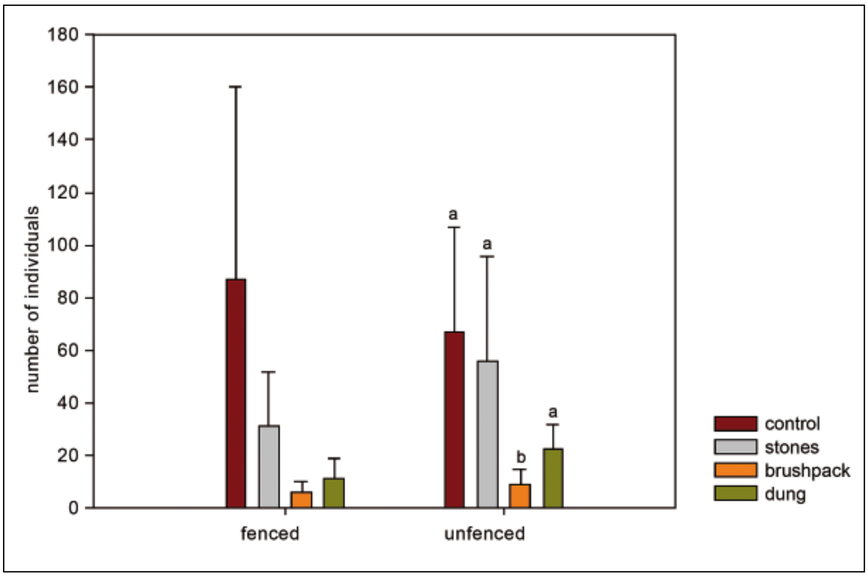


Fig. 8: Means (+SD) of the total number of perennials at fenced and unfenced subplots at Soebatsfontein on the farm Patrysegat in 2005, one year after installation of treatments. Different letters above bars indicate significant differences between treatments according to LSH with Bonferroni-Holm correction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

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.

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

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

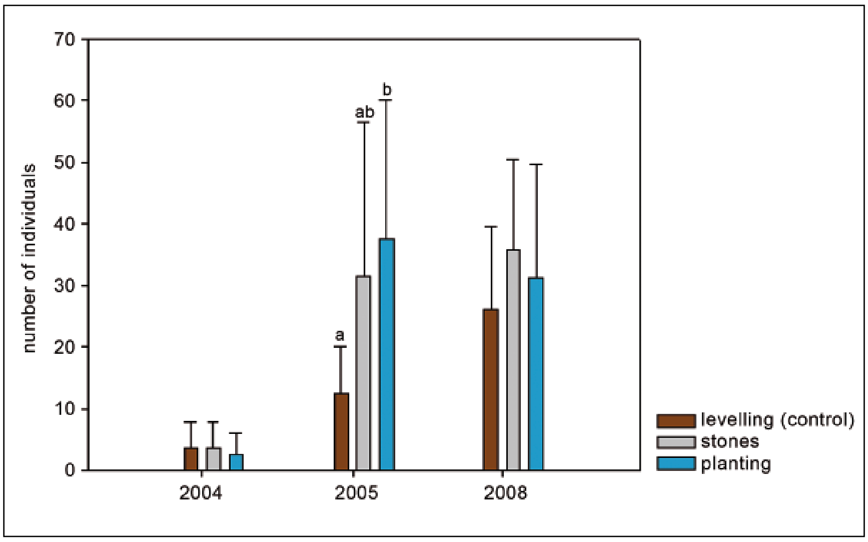


Fig. 9: Means (+SD) of the number of all plant individuals on restoration plots in quartz fields (*Cephalophyllum spissum* community) in the Knersvlakte. A treatment effect was indicated by Kruskal-Wallis tests for the mean number of individuals in 2005. Different letters above bars indicate significant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

[U. Schmiedel, T. Linke, R. Christiaan, T. Falk, A. Gröngröft, N. Kunz, T. Labitzky, J. Luther-Mosebach, S. Meyer, I.U. Röwer, B. Vollan & B. Weber]

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.

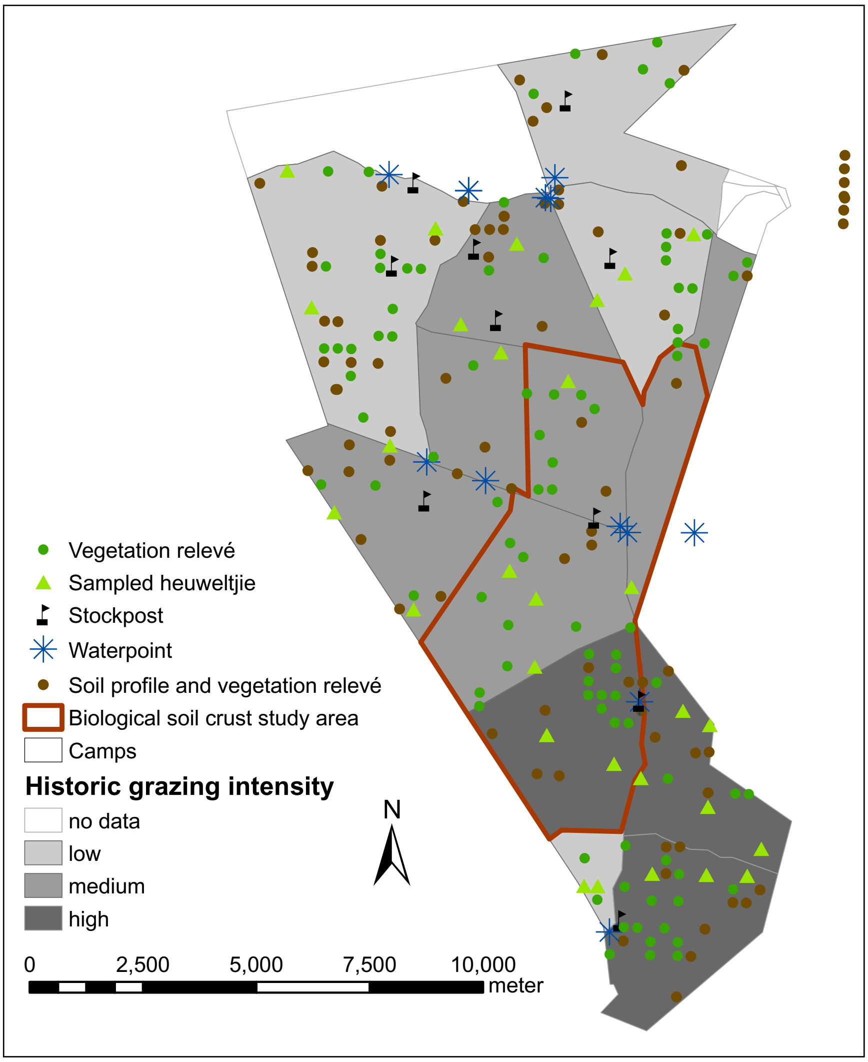


Fig. 10: Historical grazing intensity classes per camp and the distribution of plots for vascular plant relevés on the Soebatsfontein commonage.

- 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.

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 cooperation 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

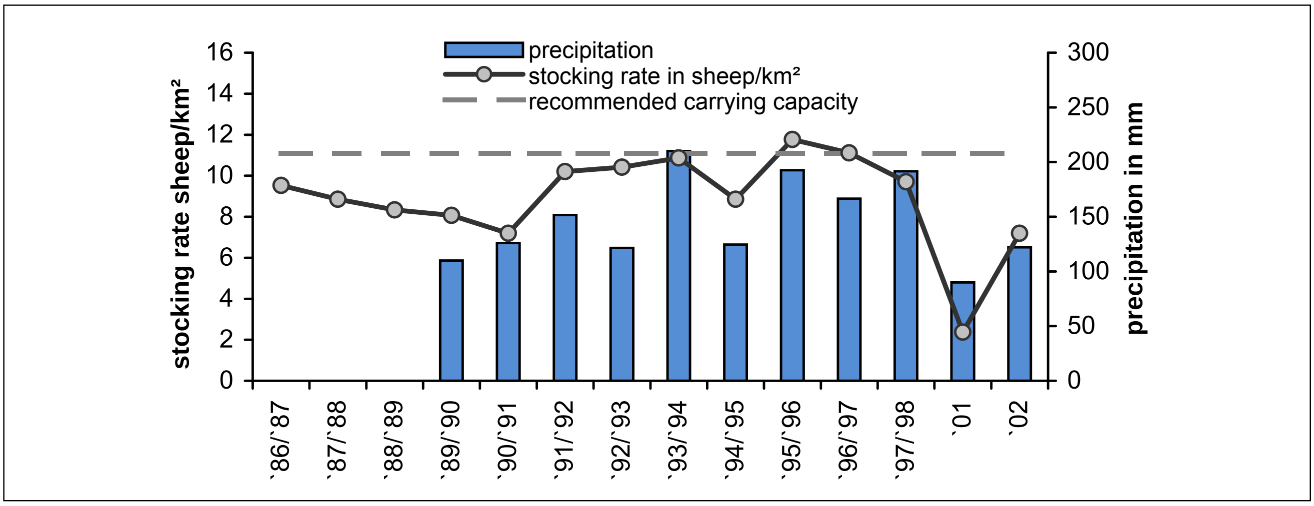


Fig. 11: The fluctuation of stocking rates (livestock use-intensity) in relation to annual precipitation on the Soebatsfontein commonage. The land was transferred to the Soebatsfontein community in 2000. The data previous to 2000 reflect the number of livestock maintained by De Beers on the area Sources: 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.

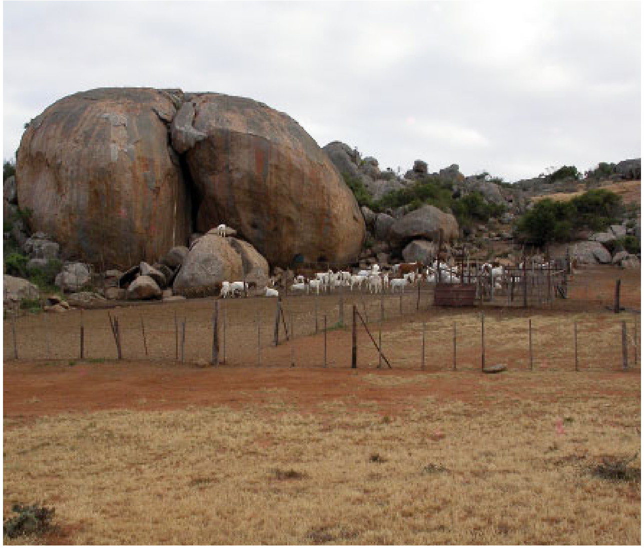


Photo 19: Stock post at Soebatsfontein commonage. Photo: Bettina Weber.

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

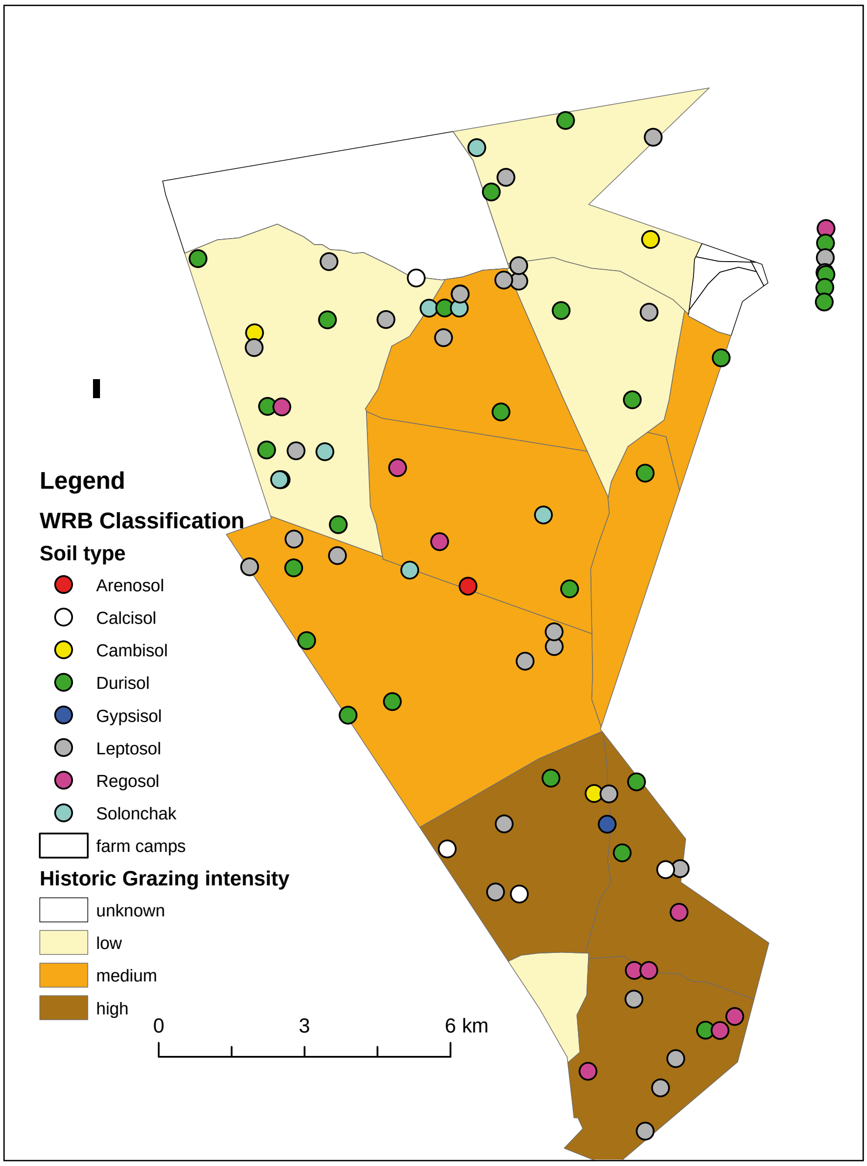


Fig. 12: Distribution of soil types on the Soebatsfontein commonage.

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

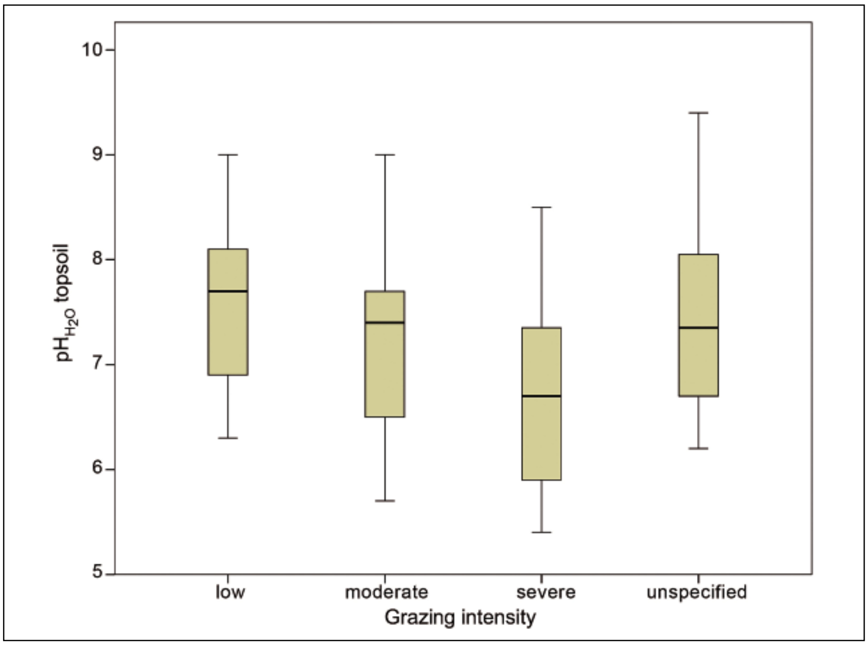


Fig. 13: Topsoil pH under different historical grazing intensities: low (*N* = 26), moderate (*N* = 25), severe (*N* = 24), and unspecified (*N* = 16).

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.

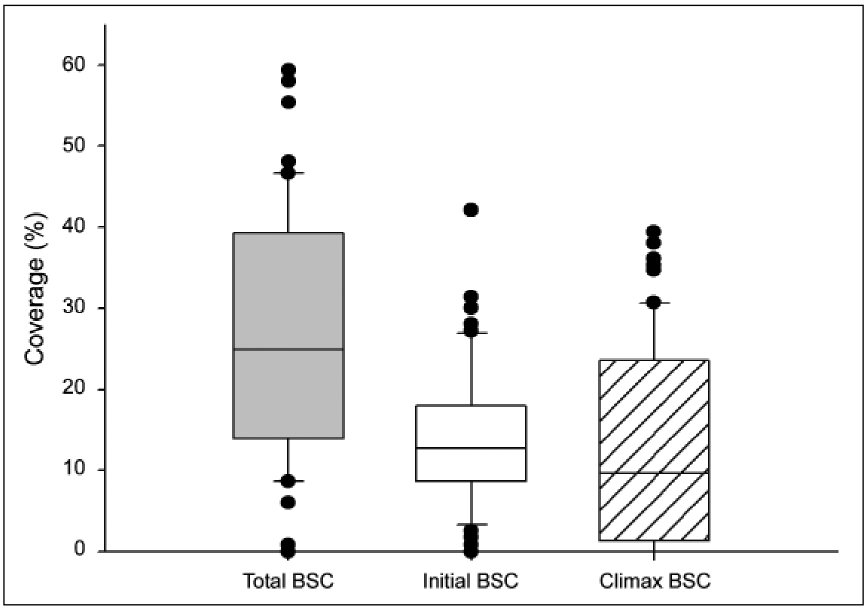


Fig. 14: Cover of the different types of biological soil crusts (BSC; $N = 60$) on the Soebatsfontein commonage.

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, $N = 60$

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 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.

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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.

Fragmented Cape Lowland landscape. Photo: J. Dengler.

Part IV

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Keeping the Cape Lowland archipelago afloat

Cornelia B. Krug*, Roland Brandl, Carmen Boonzaier, Juliano Cabral, Karen J. Esler, Paul B.C. Grant, Steffen Heelemann, Anne Horn, Manfred Keil, Raphael Y. Kongor, Jork Meyer, Henning Nottebrok, Peter Poschlod, Christoph Reisch, Sascha Rösner, Michael J. Samways, Frank M. Schurr & Sven Vrdoljak

Summary: The lowland habitats of the Western Cape, South Africa, have been severely impacted by human activities, particularly in the last three centuries. The natural vegetation is highly transformed and fragmented, and the remaining remnants are threatened by further conversion for housing or agriculture, invasive alien species and global climate change. In contrast to adjacent mountainous regions, the Cape lowlands are poorly protected, and few statutory reserves exist. In many lowland vegetation types, conservation targets for the protection of species are unattainable, as a significant proportion of the natural habitat has already been transformed. In addition, more than three-quarters of the Cape lowlands are in private hands, making new approaches to conservation necessary.

We aimed to determine the effects of habitat transformation and fragmentation on species diversity and on populations, as well as the resulting assemblage changes and their impact on ecological processes such as pollination and dispersal. The research used a number of different taxa (plants, insects, birds, small mammals) and investigated their role in ecosystem and genetic diversity.

We could demonstrate negative effects of habitat transformation and fragmentation on biodiversity and connected ecosystem processes. However, our research also highlighted the contribution of small remnants to the overall biodiversity of the region and the necessity to conserve and manage them appropriately. Successful biodiversity conservation should not take a binary ‘reserves vs. utilised’ approach, but instead should consider the entire landscape as a heterogeneous system that must be managed accordingly. We therefore suggest ways to improve the management of habitat fragments in the Cape lowlands, and propose approaches to successfully conserve and maintain the biodiversity of this unique region.

Table 1: Description of the three vegetation units investigated

	Langebaan Dune Strandveld	Atlantis Sand Fynbos	Swartland Shale Renosterveld
Topography	Flat to slightly undulating coastal dune systems and stabilised inland duneveld Elevations sea-level to 150 m	Moderately undulating to flat plains Elevations of 40–250 m	Moderately undulating plains and valleys Elevations of 50–350 m
Vegetation Structure	Closed, evergreen, sclerophyllous shrubland Herbaceous flora in gaps	Dense, moderately tall ericoid shrubland Emergent, tall sclerophyllous shrubs Open, short restioid stratum	Leptophyllous or low, open shrubland Geophytes and grasses in understorey and gaps Thicket vegetation on Heuweltjies (underground termitaria)
Soil	Deep tertiary to recent sands and marine calcrete	White or yellow acidic, tertiary, grey regid sands	Clay soils derived from Malmesbury group shales
Climate	Cyclonic rainfall almost exclusively in winter MAP 230–335 mm MAT 16.2°C DMax 26.1°C (February) DMin 7.8°C (July) Fog and dew in summer and autumn Infrequent frosts	Winter rainfall (mainly May–August) MAP 290–660 mm (mean 440 mm) MAT 16.6°C DMax 27.9°C (February) DMin 7.0°C (July) 3 frost days p.a.	winter rainfall (mainly May–August) MAP 270–670 mm MAT 17.2°C DMax 29.6°C (February) DMin 6.3°C (July) Mist in winter 3–4 frost days p.a.

MAP = Mean annual precipitation, MAT = Mean annual temperature, DMax = Daily maximal temperature, DMin = Daily minimal temperature.
Information extracted from Rebelo et al. (2006).

5.1 Introduction

Introduction to the study region

The western coastal lowlands of the Cape Floristic Region (CFR) stretch from the Olifants River in the north to False Bay in the south, and are bordered by the Cape Fold Mountains to the east (Fig. 1). They comprise flat to moderately undulating plains and low mountain foothills, with elevations ranging from sea level to 350 m a.s.l. The region experiences a Mediterranean-type climate with dry hot summers and cool wet winters. The main vegetation types in the region are dune Strandveld, Sand Fynbos and Renosterveld (Rebelo et al. 2006). Research was mainly conducted in three vegetation units (sensu Mucina and Rutherford 2006)—Langebaan Dune Strandveld, Atlantis Sand Fynbos and Swartland Shale Renosterveld (see Table 1). Dune Strandveld occurs on stabilised Pleistocene dunes and calcareous soils of marine origin, Sand Fynbos on acid aeolian sands, while Renosterveld is associated with shale-derived soils. The boundary and transition between Strandveld and Sand Fynbos is determined by topography and succulence, while the boundary between Renosterveld and Sand Fynbos is determined by soil type (clay-derived soils are richer in nutrients, especially potassium), and amount of rainfall received (Rebelo et al. 2006).

What happened and why?

Humans have lived in the Cape lowlands for tens of thousands of years, but significant impacts have only occurred in the last few hundred years (Krug & Krug 2007, Newton 2008). Based mainly on differences in soil fertility, anthropogenic impacts and thus transformation of natural vegetation differ markedly between lowland vegetation units. Conservation status and threats to the three vegetation types are summarised in Table 2, while the current extent of the three vegetation types as assessed to the 2003 status (C.A.P.E. Co-ordination Unit 2003) is depicted in Fig. 2, and their conservation status is illustrated in Fig. 3.

Renosterveld, which is associated with "fertile" clay soils coupled with a rainfall regime favourable for agriculture, has been the hardest hit by human activities.

Fig. 1: Extent of the western coastal lowlands of the CFR, indicating the distribution of the three main vegetation types, renosterveld, strandveld and sand fynbos. Data from Mucina & Rutherford (2006), and Landsat image of 2007 of the region.

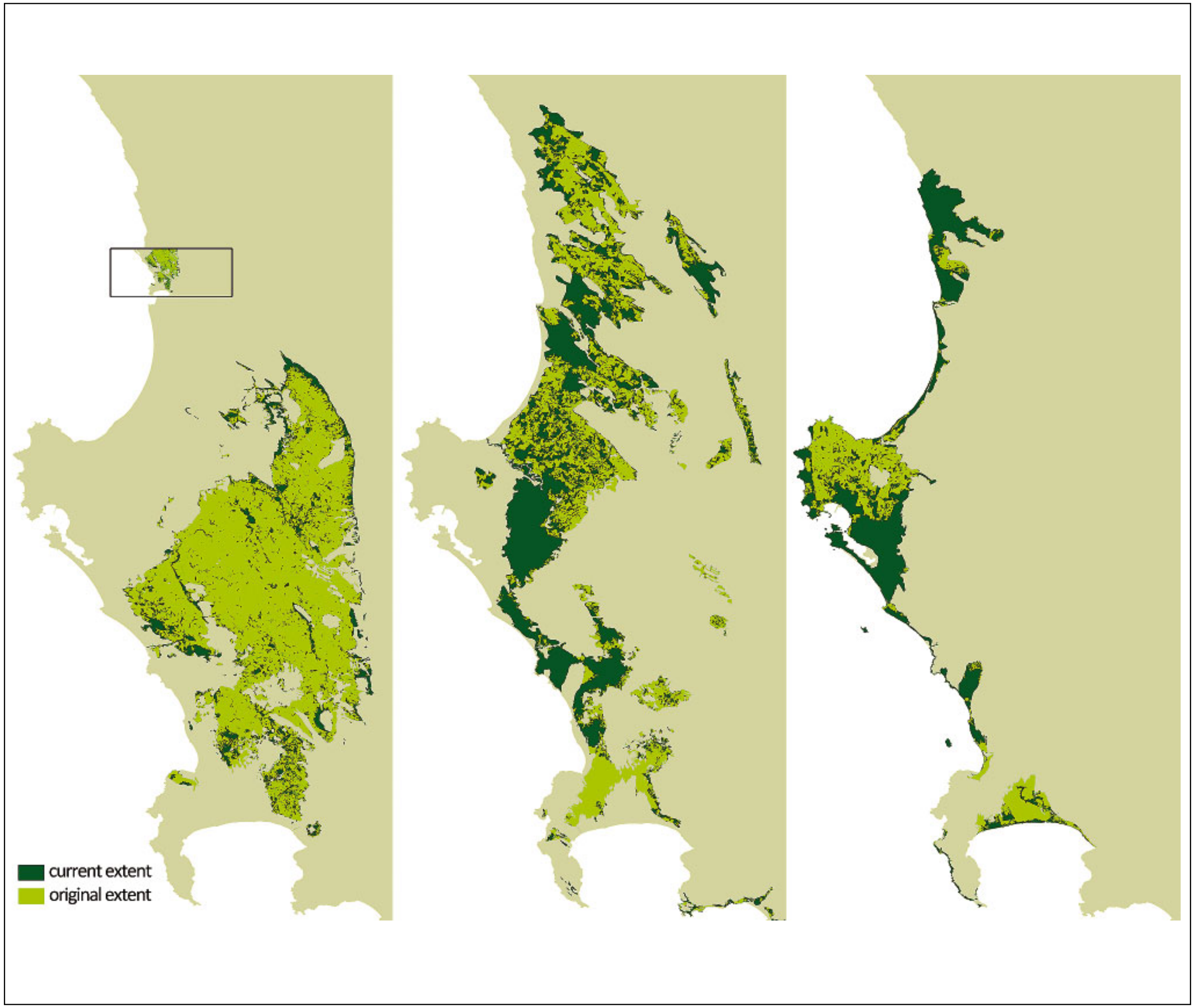


Fig. 2: Current (dark green) and original (light green) extent of Renosterveld (a), Sand Fynbos (b) and Strandveld (c). Coverage extracted from C.A.P.E. Co-ordination Unit (2003) and Mucina & Rutherford (2006).

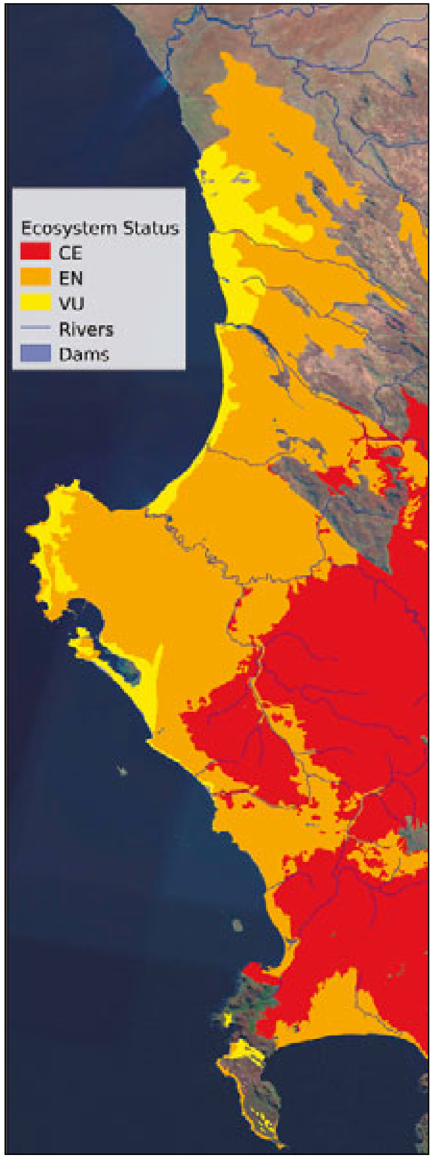


Fig. 3: Ecosystem status of the western coastal lowland vegetation. Red: critically endangered, orange: endangered, yellow: vulnerable. Data from Rouget et al. (2005).

Table 2: Conservation status and threats to three vegetation units investigated

	Langebaan Dune Strandveld	**Atlantis Sand Fynbos**	**Swartland Shale Renosterveld**
Conservation Status	Vulnerable	Vulnerable (endangered)*	Critically endangered
Biodiversity Target**	24%	30%	26% (unattainable)
% Area under protection	30% Rocherpan Nature Reserve	4% Riverlands Nature Reserve Pella Nature Reserve Paardenberg	0.5% No statutory reserves
% Area transformed/ Type of Transformation	35% Cultivation Urban sprawl	40% Cultivation Urban sprawl Pine and gum plantations	90% Cultivation
Threats	Infestation by woody aliens *Acacia cyclops*, *A. saligna*	Infestation by woody aliens *A. saligna*, *A. cyclops*, *Eucalyptus* spp., *Pinus* spp. Invasion by alien annual grasses	Infestation by alien grasses (*Avena*, *Briza*, *Bromus*, *Lolium*, *Phalarius* and *Vulpia*), and forbs (*Erodium cicutarium*, *E. moschatum*, *Echium plantagineum* and *Petrorhagia prolifera*)
Special Adaptations	Succulence (climate) Fleshy fruits (climate)	Fire ephemerals (fire) Serotiny (fire, nutrient poor soils) Obligate resprouting (fire) Obligate re-seeding (nutrient poor soils) Smoke induced seed germination (fire) Myrmecochory (nutrient poor soils) Sclerophylly (nutrient poor soils) Cluster roots (nutrient poor soils) Carnivory by plants (nutrient poor soils) Bird pollination (nutrient poor soils)	Dicot geophytes (fire and grazing) Geophyte - mole rat co-evolution Large mammal herbivory Pollination by long-tongued flies, monkey beetles
Processes potentially threatened by fragmentation	Seed dispersal (birds)	Fire (frequency) Pollination (birds) NB: single-pollinators are norm	Herbivory Pollination (insects) NB: single-pollinators are norm

* according to Rouget et al. 2005,
** percent of vegetation unit required to conserve a regions biodiversity (Pressey et al. 2003, Desmet & Cowling 2004).
Information extracted from Rebelo et al. (2006).

Although humans have impacted on Renosterveld for thousands of years, the major transformation of the vegetation began with the arrival of the European settlers in the mid-1600s (Krug & Krug 2007). Apart from clearing natural vegetation for cropping on a large scale, livestock was grazed in the vegetation continuously (in contrast to the nomadic grazing practiced by the Khoekhoen), the natural fire regime was suppressed early on, and most of the large herds of indigenous animals present in the vegetation were hunted to extinction (Krug & Krug 2007, Newton 2008), thus irrevocably changing ecological processes. Today, more than 90% of the original extent has been transformed, and less than 0.5% of the remaining vegetation is conserved (Rebelo et al. 2006). Renosterveld remnants are further threatened by the invasion of alien grasses and forbs, and, in agricultural areas, are subjected to spray drift from herbicide and pesticide application and fertiliser run-off (Sharma et al. 2010, Donaldson et al. 2002).

Transformation of both Sand Fynbos and Strandveld is much more recent and much less severe than that of Renosterveld. Sand Fynbos has mainly been transformed for cultivation, timber plantations, and urban areas, with the degree of transformation varying considerably between types of Sand Fynbos (Rebelo et al. 2006). The natural vegetation is invaded mainly by *Acacia saligna* and *A. cyclops*, which were used for dune stabilisation in the early 1900s (Rebelo et al. 2006). The remaining vegetation is threatened by further invasion of woody alien species (Rouget et al. 2003a), as well as alien annual grasses (Holmes & Richardson 1999). Transformation of Strandveld is mainly due to cultivation and urban development, especially along the coastline, while the remaining vegetation is threatened by invasion of woody aliens, primarily *A. cyclops* (e.g. Mugabe 2008).

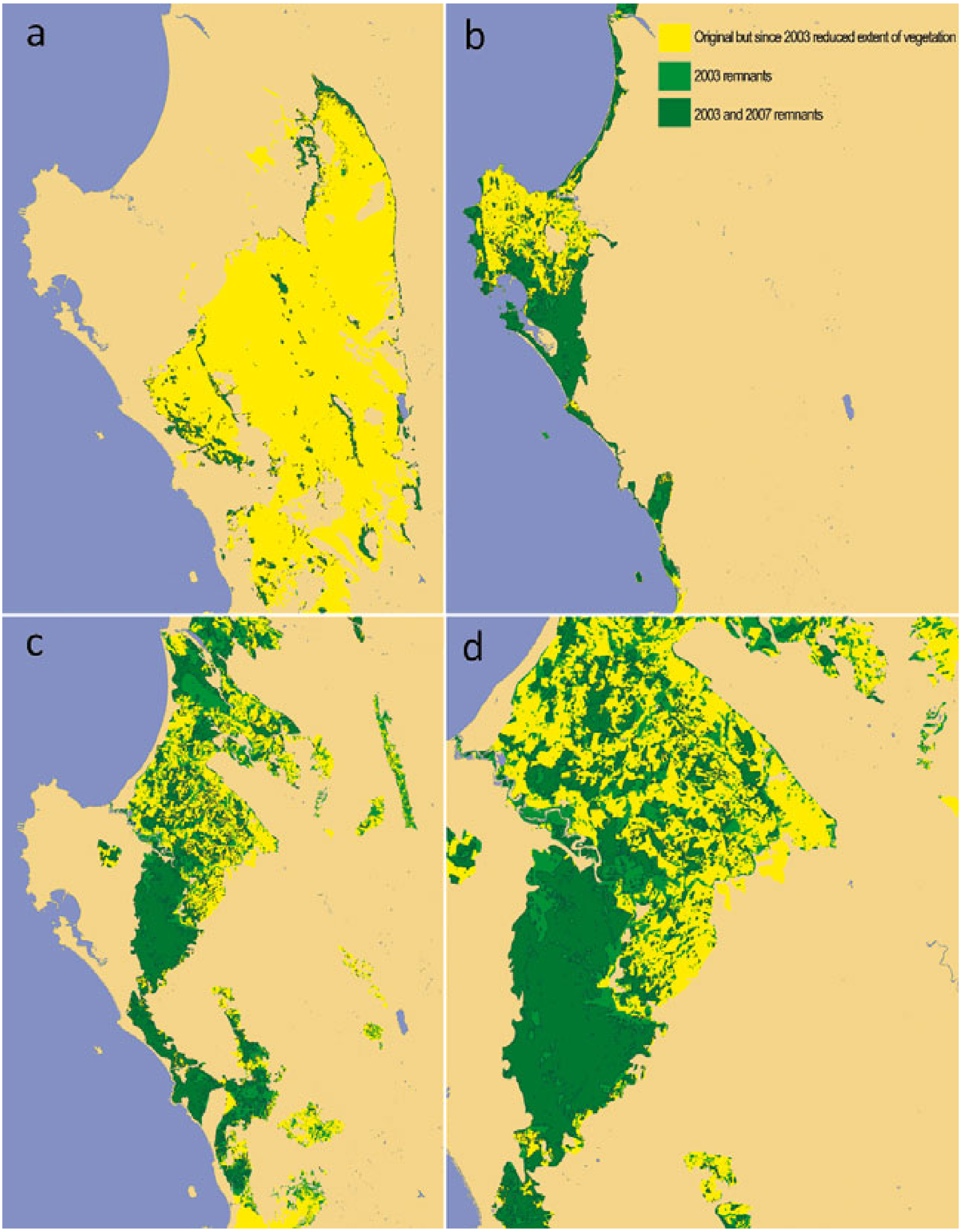


Fig. 4: Changes in natural vegetation cover between 2003 and 2007. a) Renosterveld, b) Strandveld, c) Sand Fynbos, d) sub-scene of the Strandveld around the community of Hopefield. Original but since 2003 reduced extent of vegetation in yellow, 2003 remnants in light green and dark green, and 2007 remnants in dark green.

What have we now?

Despite the fact that the Cape lowland vegetation units are considered severely threatened, habitat transformation is still ongoing. Landsat TM data of two seasons, of August 2006 and of February 2007, was used to observe further transformation in the mapped remnant layers, available for the status of 2003 (C.A.P.E. Co-ordination Unit 2003), for the three vegetation units. A rule based classification with thresholding was applied, using the spectral information of the Landsat TM bands 3 and 4 (Visual Red and Near Infrared) of both seasons. The thresholds for separating natural vegetation from areas newly transformed to agricultural use or settlements were optimised separately for the remnant layers of Renosterveld, Sand Fynbos, and Strandveld. By using this thresholding approach, the burnt areas of natural vegetation (damaged by the fires of 2003) could also be included in the assessed changes. As the remnants in Renosterveld vegetation are situated mainly in hilly terrains and at mountain slopes with different illumination, the automatic classification had to be followed by a manual post-processing and direct comparison of Landsat data of 2003 and 2007. Fig. 4 documents the most recent changes in natural vegetation cover from 2003 to 2007 resulting from this assessment.

Renosterveld is nearly 95% transformed. Mainly, only small, isolated patches remain. The large patches, which do exist, are mainly elongated in shape, and are located at the periphery of the original vegetation, and often represent eco-tonal vegetation. Only five fragments greater than 1,000 ha remain in this vegetation unit (Table 3). The average fragment size is about 17.2 ha. Furthermore, vegetation loss is ongoing, mainly at the edges of the remaining fragments. Between 2003 and 2007, the remnants were reduced by about 0.8% in relation to the original vegetation (Table 3).

Sand Fynbos and Strandveld are much less transformed than Renosterveld. In terms of Sand Fynbos, only about 43% of the area was transformed in 2003, with large tracts of contiguous vegetation remaining. The five largest contiguous tracts have sizes between about 8,000 ha and 52,000 ha (Table 3). In 2003, the average fragment size was about 31 ha. However, in some areas, e.g. within the environs of the City of Cape Town, only small isolated remnants remain, and these are distributed throughout the area. Recently, however, a high degree of transformation has taken place in Sand Fynbos, especially in the northern parts (Fig. 4), where the extent of natural vegetation has been considerably reduced. The percentage of remnants was reduced from about 56% to 33% (Table 3).

Table 3: Area statistics and some fragment statistics for the remnants of the three vegetation types

	Renosterveld	Sand Fynbos	Strandveld
Maximum fragment size (2003) in ha	2953.6	51660.3	27390.6
Maximum fragment size but five (2003) in ha	1185.9	7927.8	4302.7
Average fragment size in 2003 (ha) *	17.2 (25.3)	31.52 (42.5)	48.34 (67.6)
Summarised size of remnants in 2003 **	397.1	2326.66	963.6
Summarised size of remnants in 2007 ***	347.0	1350.9	783.9
Percentage of remnant natural vegetation (2003) **	6.7%	56.8%	58.8%
Percentage of remnant natural vegetation (2007) ***	5.9%	33.0%	47.8%

The area statistics relies on the investigated sub-scene of 135 km by 180 km shown in Fig. 5.
* in brackets: not accounting fragments below 900 m² (1 pixel size of Landsat TM),
** as found in the rasterised data (sqkm),
*** as found in the classified raster data (sqkm).

Considering this high amount of remnant reduction, the large burnt areas of Sand Fynbos in the northern parts, about 20 km south-east of Elandsbay, need to be taken into account. These areas are still integrated in the Sand Fynbos remnant layer of 2003, as the fire took place in March of 2003 (Magidi 2010). By the threshold approach applied on the Landsat data of 2006/2007, the burnt areas were included in the reduced remnant areas as non-intact natural vegetation. The burnt areas are not really transformed, but severely degraded, and the high risk exists that alien species like *Acacia saligna* and *A. cyclops* invade the region and dominate future vegetation cover. In his study on landuse dynamics on an area of about 60 km by 60 km South of Elandsbay, based on Landsat data of 1990, 2004, and 2007, Magidi (2010) did not integrate these burnt areas into the transformation processes. He took also into account a regeneration of former agricultural used areas to natural vegetation, which, however, has to be done for longer periods.

For Strandveld, the picture is similar to Sand Fynbos. About 41% of the original vegetation extent was transformed up to 2003, but large tracts of contiguous vegetation remain, especially in the centre (around the West Coast National Park and Langebaan). The five largest contiguous tracts have sizes between about 4,300 ha and 27,400 ha (Table 3). In the City of Cape Town, the vegetation unit is restricted to small isolated remnants (Fig. 4), as it is in the Saldanha Bay area. As resulting by the Landsat evaluation, a higher recent transformation (2003–2007) can be observed (Fig. 4). The degree of conversion for the Strandveld rose up from about 41% to about 52% (Table 3).

Conservation challenges in the Western Cape Lowlands

As a result of the considerable human impacts and extensive habitat transformation, biodiversity conservation in the Cape Lowlands faces significant challenges. Threats include transformation by urban and agricultural expansion, invasion by alien species and global climate change. Although 20% of the CFR is formally protected, the coverage of protected areas is biased, towards areas topographically and climatically unsuitable for agriculture. The lowlands themselves are poorly protected (less than 5% of the area), and very few statutory reserves exist. This bias in protection results in inadequate representation of many biodiversity patterns and processes (Rouget et al. 2003a, b). Further agricultural expansion is most likely to affect these poorly protected lowland habitats (e.g. Fairbanks et al. 2004). High levels of endemism, high species turnover, and the irreplaceability of most habitat types in the CFR mean that even small remnants are likely to be valuable in terms of achieving conservation planning goals (Rouget et al. 2003a, b).

Three-quarters of the CFR is in private hands. High land values and the high degree of fragmentation largely preclude the expansion of existing, formally protected areas (Fairbanks et al. 2004). Therefore, the conservation of biodiversity outside of reserve areas is an important, if not the only available option, for achieving conservation targets in the lowlands of the CFR (Kemper et al. 1999, Cowling et al. 2003, Fairbanks et al. 2004). Recently, initiatives such as the CapeNature Stewardship Programme, and the Biodiversity and Wine Initiative (BWI) have been founded to seek alternative conservation measures that involve landowners, particularly farmers, in the management and protection of natural and semi-natural remnants.

The basic principles of maintaining heterogeneity and connectivity within agricultural landscapes form a framework for effective and adaptive management of biodiversity at the landscape level (Samways 2007). In practice however, ecological processes and functioning within these remnants and the magnitude of their contribution to biodiversity conservation at the regional or landscape level are largely unknown and often difficult to assess (Tscharntke et al. 2005). Information on the extent of biodiversity in the region, and the effects of landuse, habitat transformation, and habitat fragmentation on species, communities, and ecological processes is crucial to guide conservation planning in the Cape Lowlands, and to provide recommendations for landuse management and biodiversity conservation in a multi-use landscape.

5.2 Diversity disrupted

What are the effects of habitat transformation and fragmentation on biodiversity?

Background

The effect of habitat transformation and fragmentation on biodiversity have been investigated in numerous studies on a range of taxa across the globe (for reviews, see Andren 1994, Debinski & Holt 2000). Many of these studies have found confounding effects, such as site history, disturbance regime, and time since fragmentation, that mask true fragmentation effects (review by Ewers & Didham 2006). Very few studies, however, have been conducted on this topic in the Western Cape Lowlands (but see: Cowling & Bond 1991, Kemper et al. 1999, 2000, Donaldson et al. 2002, Pauw 2004, 2007). The results presented here are some of the first observations of the effects of habitat fragmentation and transformation on certain taxa in the Western Cape Lowlands.

Research was centred around the BIOTA Observatories at Rocherpan Nature Reserve (Observatory S29), Riverlands Nature Reserve (S31) and Elandsberg Private Nature Reserve (S32) as well as Tygerberg Nature Reserve, and thus focussed on the Langebaan Dune Strandveld, Atlantis Sand Fynbos, Swartland Alluvium Fynbos and Swartland Shale Renosterveld vegetation units respectively (Mucina & Rutherford 2006). For comparative purposes, some of the studies also covered other vegetation units within the primary vegetation types of Strandveld, Fynbos and Renosterveld. Depending on the key questions addressed, research was conducted on a number of satellite sites scattered around four protected areas (dubbed “mainland”), each of which was representative of one of the four main vegetation units outlined above. A description of these mainland sites located within protected areas can be found in Table 4.

Fragment size effects on plants

Fragment size had a negative effect on plant species richness in all three vegetation units investigated. However, this negative fragment size effect was more evident in Atlantis Sand Fynbos than in Swartland Shale Renosterveld or Langebaan Dune Strandveld (Kongor 2009; Table 5). In Sand Fynbos, plant species richness decreased with decreasing fragment size, while in Renosterveld and Strandveld, species richness was only considerably lower in the smallest (8 ha) of the fragments investigated. The fragmentation effect in Renosterveld and Strandveld was masked by site disturbances (mainly grazing by game and sheep, respectively). In Swartland Shale Renosterveld, plant species richness was highest in the medium-sized fragment (70 ha), which was grazed, than in the other fragments. In Langebaan Dune Strandveld, the relatively light disturbance caused by sheep grazing was a likely contributor to the observed higher plant species richness of the large- (70 ha) and medium-sized (18 ha) fragments compared to the mainland (930 ha). Previous studies conducted in Renosterveld (e.g. Kemper et al. 2000) found similar confounding effects on the impact of fragment size on species richness. Species diversity (as calculated with Shannon-Wiener and Gini-Simpson Diversity index), produced similar results (Kongor 2009).

Although species richness and diversity are the most often used measures to determine changes in ecosystems, plant functional traits are in fact better predictors of ecosystem response to local changes, such as habitat transformation and fragmentation (Lavorel & Garnier 2002, Cornelissen et al. 2003). We, therefore, also tested the effects of fragment size on objectively and subjectively selected plant trait combinations (plant functional types (PFTs), listed in Table 6. These included long- or short-distance dispersed specialist- or generalist- pollinated, non-dioecious or dioecious, perennial seeders or resprouters; long- or short- distance dispersed, specialist- or generalist-pollinated, annual seeders. For more details on how these PFTs were derived, see Kongor (2009). Overall, fragment size effects on PFT richness and diversity (calculated with Gini-Simpson index) were similar to those observed on

Table 4: Description of the “mainland” sites representing the four vegetation types (adapted from Kongor 2009)

“Mainland” site	Protection Status	Size (ha)	Vegetation Unit	Special habitats	Landuse history	Fire history	Alien plant species	Matrix type (resistance value*)
Rocherpan Nature Reserve (S29)	Provincial Nature Reserve (CapeNature), 1967; marine protected area, 1988	930 ha	Langebaan Dune Strandveld	Seasonal wetland (pan)	live stock (cattle) grazing until 1967	No fire since the 1960s	Some annual grasses (*Bromus*, *Avena*)	Wheat and potato fields (75); minor road (50)
Riverlands Nature Reserve (S31)	Provincial Nature Reserve (CapeNature), 1986	1100 ha	Atlantis Sand Fynbos	Seasonally waterlogged areas (seepages, vleis)	Some crop farming, no grazing	Last extensive fires in March 2005 and 2006; natural fires every 4–25 years (average 7 years)	*Acacia saligna*; regular clearing efforts	*Acacia saligna* (50); wheat fields (75)
Tygerberg Nature Reserve	Municipal NatureReserve (City of Cape Town), 1973	600 ha	Swartland Shale Renosterveld	Thicket vegetation on heuweltjies (termitaria)	Grain and grape farming since the 1700s, ending 1948/1963	Partly burnt in 1996 and 2000	Annual grasses (*Briza*, *Avena*), as well as *Pinus* and *Echium plantagineum*	Settlement (75–100); vineyards (75)
Elandsberg Private Nature Reserve (S32)	Private Nature Reserve (1973); Contractual Provincial Nature Reserve (2009)	3600 ha, lowland portion 1000 ha	Swartland Alluvium Fynbos	Seasonal waterlogged areas (vlei); thicket vegetation on heuweltjies (termitaria)	Live stock (sheep) grazing until 1972	Regular fires, mainly in mountain section, lowlands partly burned in 1995	Some annual grasses (*Bromus*, *Avena*)	Wheat and canola fields (75); minor road (50)

* resistance values from Jonas et al. (2006)

Table 5: Species richness in three modified 50 m x 20 m (i.e. 1,000 m^2) Whittaker plots in the four fragments of the three vegetation units (adapted from Kongor 2009)

Vegetation unit	Mainland	Large fragment	Medium-sized fragment	Small fragment	Mean ± SD
Langebaan Dune Strandveld	42 (34 ± 8) (Rocherpan, 930 ha)	64 (49 ± 13) (Part of St. Helena Fontein, 70 ha)	52 (40 ± 8) (Part of St. Helena Fontein, 18 ha)	42 (31 ± 8) (Modderfontein, 8 ha)	50 ± 10
Atlantis Sand Fynbos	74 (49 ± 16) (Riverlands, 1100 ha)	53 (40 ± 8) (Pella, 600 ha)	41 (29 ± 8) (Kalbaskraal, 37 ha)	41 (29 ± 8) (Camphill Village, 16 ha)	52 ± 16
Swartland Shale Renosterveld	46 (27 ± 8) (Tygerberg, 600 ha)	67 (44 ± 12) (Mereendal, 300 ha)	101 (76 ± 17) (ClaraAnna Fontein, 70 ha)	25 25 (15 ± 5) (Van Riebeeckshof, 15 ha)	60 ± 33

plant species richness and diversity (Tables 7 and 8). Fragment size reduction had a greater effect on PFT diversity than on PFT richness, particularly in Renosterveld. In Fynbos, PFT richness decreased only slightly with decreasing fragment size, indicating a high functional redundancy (i.e. PFTs or trait combinations are represented by many species). In Renosterveld and Strandveld, grazing again confounded fragment size effects and PFT richness and diversity was highest in the medium-sized Renosterveld fragment (grazed by game) as well as in the sheep-grazed large and medium-sized Strandveld fragments. PFT richness and diversity were lowest in the smallest Renosterveld fragment than in the other Renosterveld sites (and all other sites investigated). Overall, changes in species richness, and PFT richness and diversity are not linked only to fragment size, but are also influenced by a number of other factors, which in this case includes mainly the current disturbance regime and site history.

We also investigated whether trait assembly patterns (trait-convergence vs. trait-divergence) were found in the fragmented Cape lowland vegetation in order to understand the connection between traits and assembly processes under various site factors associated with habitat fragmentation (Kongor et al., under review). Trait-convergence assembly pattern (TCAP) is expressed when external factors governing a species’ adaptation select for species with similar traits, while trait-divergence assembly pattern (TDAP) is revealed when plant communities contain species with less-similar traits or if the coexistence of species is constrained by their trait similarity. Traits were selected based on species’ response

Table 6: Plant functional types and/or traits (PFTs) lost from the four fragments of the three vegetation units (adapted from Kongor 2009)

Atlantis Sand Fynbos (16 PFTs identified)	**Swartland Shale Renosterveld (14 PFTs identified)**	**Langebaan Dune Strandveld (15 PFTs identified)**
Mainland		
(1) long-distance dispersed, specialist-pollinated, non-dioecious, perennial seeders (*Pelargonium oenothera*) (2) long-distance dispersed, specialist-pollinated, annual seeders (*Pelargonium senecioides*)	(1) The short-distance dispersed, generalist-pollinated, dioecious resprouters (*Ischyrolepis capense*)	(1) long-distance dispersed, specialist-pollinated, annual seeders (*Pelargonium senecioides*) (2) short-distance dispersed, generalist-pollinated, dioecious resprouters (*Leucadendron brunoides* subsp. *flumenlupinum* and *Anthospermum spathulatum*) (3) short-distance dispersed, specialist-pollinated, non-dioecious resprouters (mostly geophytes e.g. *Bulbine praemorsa*, *Caesia sp.* and *Cyanella hyacinthioides*)
Large fragment		
(1) long-distance dispersed, specialist-pollinated, annual seeders (*Pelargonium senecioides*) (2) short-distance dispersed, specialist- pollinated, non-dioecious resprouters (*Babiana* sp.) (3) short-distance dispersed, specialist-pollinated, dioecious perennial seeders (*Leucadendron cinereum*)	All 14 PFTs represented	(1) long-distance dispersed, specialist-pollinated, non-dioecious perennial seeders (*Microloma sagittatum*) (2) long-distance dispersed, specialist-pollinated, dioecious perennial seeders (*Diospyros glabra* and *Euclea racemosa*)
Medium-sized fragment		
(1) long-distance dispersed, specialist-pollinated, non-dioecious perennial seeders (*Pelargonium oenothera*) (2) long-distance dispersed, specialist-pollinated, annual seeders (*Pelargonium senecioides*) (3) long-distance dispersed, generalist-pollinated, annual seeders mainly asteraceous herbs (e.g. *Felicia tenella*, *Gymnodiscus capillaries*, *Helichrysum indicum*, *Pseudognaphalium undulatum*, *Senecio elegans*, *Ursinia anthemoides*) and Poaceae (e.g. *Pentaschistis patula*) (4) short-distance dispersed, generalist-pollinated, annual seeders (*Nemesia affinis*, *Wahlenbergia androsacea*)	(1) The short-distance dispersed, generalist-pollinated, dioecious resprouters (*Ischyrolepis capense*)	(1) long-distance dispersed, specialist-pollinated, dioecious perennial seeders (*Diospyros glabra* and *Euclea racemosa*) (2) short-distance dispersed, generalist-pollinated, dioecious resprouters (*Leucadendron brunoides* subsp. *flumenlupinum* and *Anthospermum spathulatum*)
Smallest fragment		
(1) long-distance dispersed, specialist- pollinated, dioecious resprouters (*Leucadendron lanigerum* subsp. *lanigerum*) (2) long-distance dispersed, specialist-pollinated, non-dioecious, perennial seeders (*Pelargonium oenothera*) (3) short-distance dispersed, specialist pollinated, non-dioecious perennial seeders (4) short-distance dispersed, specialist-pollinated, dioecious, perennial seeders (*Leucadendron cinereum*) (5) short- distance dispersed, generalist-pollinated, annual seeders (*Nemesia affinis*, and *Wahlenbergia androsacea*)	(1) long-distance dispersed, generalist- pollinated, dioecious perennial seeders (*Rhus* species, *Arctopus echinatus*, and *Cissampelos capensis*) (2) long-distance dispersed, specialist- pollinated, annual seeders (*Crassula strigosa*) (3) short-distance dispersed, generalist- pollinated, dioecious resprouters (*Ischyrolepis capense*) (4) short-distance dispersed, specialist- pollinated, non-dioecious resprouters mostly geophytes e.g. *Babiana stricta*, *Geissorhiza aspera*, *Cyphia*, *Moraea* and *Spiloxene* sp. (5) short-distance dispersed, specialist- pollinated, non-dioecious, perennial seeders e.g. *Salvia africana-caerulea* (6) short-distance dispersed, specialist-pollinated, annual seeders (*Hemimeris racemosa)* (7) short-distance dispersed, generalist-pollinated, annual seeders (*Sebaea exacoides*)	(1) long-distance dispersed, specialist-pollinated, non-dioecious perennial seeders (*Microloma sagittatum*) (2) short-distance dispersed, generalist-pollinated, dioecious resprouters (*Leucadendron brunoides* subsp. *flumenlupinum* and *Anthospermum spathulatum*)

Table 7: Plant functional type (PFT) richness at 1,000 m^2 in the four fragments of the three vegetation units (adapted from Kongor 2009)

	Mainland	Large fragment	Medium-sized fragment	Small fragment	Mean ± SD
Langebaan Dune Strandveld	12 (11 ± 1) (Rocherpan, 930 ha)	12 (12 ± 1) (Part of St. Helena Fontein, 70 ha)	13 (12 ± 1) (Part of St. Helena Fontein, 18 ha)	13 (11 ± 1) (Modderfontein, 8 ha)	13 ± 1
Atlantis Sand Fynbos	14 (12 ± 2) (Riverlands, 1100 ha)	13 (12 ± 1) (Pella, 600 ha)	12 (11 ± 2) (Kalbaskraal, 37 ha)	11 (10 ± 1) (Camphill Village, 16 ha)	13 ± 1
Swartland Shale Renosterveld	13 (10 ± 2) (Tygerberg, 600 ha)	14 (12 ± 2) (Mereendal, 300 ha)	13 (13 ± 1) (ClaraAnna Fontein, 70 ha)	7 (5 ± 1) (Van Riebeeckshof, 15 ha)	12 ± 3

Table 8: Plant functional type (PFT) diversity ± SD based on the Gini-Simpson Index at 1,000 m^2 in the four fragments of the three vegetation units (adapted from Kongor 2009)

	Mainland	Large fragment	Medium-sized fragment	Small fragment
Langebaan Dune Strandveld	0.871 ± 0.031 (Rocherpan, 930 ha)	0.887 ± 0.031 (Part of St. Helena Fontein, 70 ha)	0.895 ± 0.018 (Part of St. Helena Fontein, 18 ha)	0.850 ± 0.031 (Modderfontein, 8 ha)
Atlantis Sand Fynbos	0.888 ± 0.021 (Riverlands, 1100 ha)	0.882 ± 0.017 (Pella, 600 ha)	0.846 ± 0.048 (Kalbaskraal, 37 ha)	0.863 ± 0.033 (Camphill Village, 16 ha)
Swartland Shale Renosterveld	0.802 ± 0.066 (Tygerberg, 600 ha)	0.871 ± 0.019 (Mereendal, 300 ha)	0.908 ± 0.007 (ClaraAnna Fontein, 70 ha)	0.639 ± 0.083 (VanRiebeeckshof, 15 ha)

to habitat fragmentation. Therefore, we interpret our findings to mean that the traits selected are involved (though not exclusively) in the environmental filtering of species from the existing species pool in the study area which is an indication that habitat fragmentation plays a role in plant community composition and ecological functions in the Cape lowlands. Our study also revealed redundancy among traits that maximised the expression of TCAP. Since ecological redundancy enhances resilience, which is a vital element of the stability of an ecosystem, we suggest that the functional redundancy revealed by our trait analyses is an indicator of resilience of the remnant, albeit fragmented, natural vegetation in the Cape lowlands to anthropogenic pressures (Kongor et al., under review).

Insects in transformed landscapes

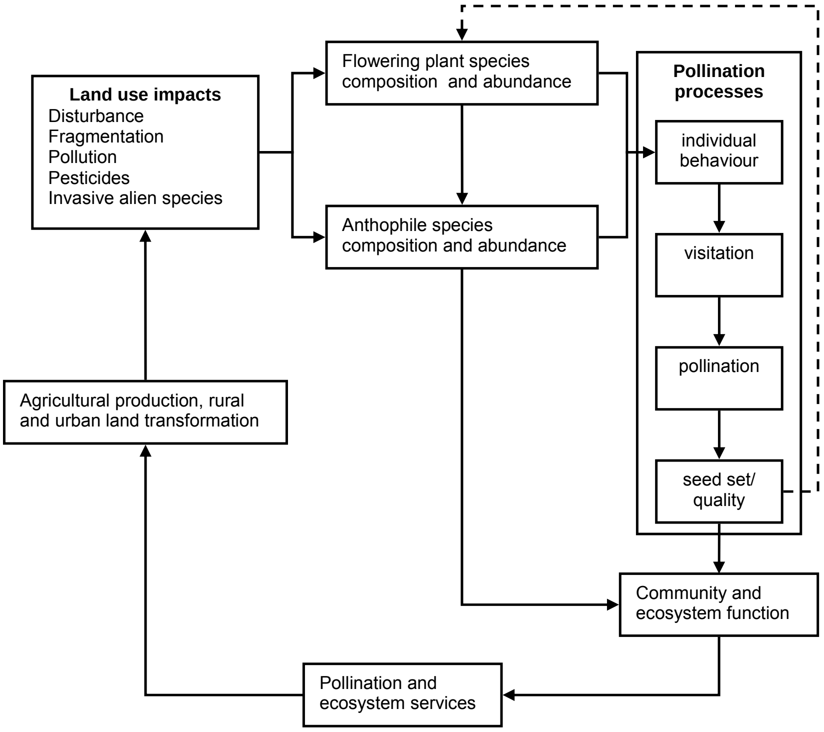
Insects and other arthropods form an integral part of most ecosystems, dominating abundance and biomass of biodiversity (Major et al. 2003). They are also responsible for providing many ecosystem services such as nutrient cycling, controlling the population of other animals through predation, maintaining plant populations, seed dispersal, and pollination, thus playing a keystone role in many ecosystems (Samways 2005). Insects are sensitive to disturbance at a number of spatial and temporal scales (Samways 2005), yet little is known about the effects of disturbance on insect assemblages in the CFR (Picker & Samways 1996, Donaldson et al. 2002).

Insect pollinators are a particularly important group, as they have the ability to affect, and be affected by both the structure and functioning of ecosystems (see Box 1). The disruption of these interactions by changes in landuse, agricultural and urban expansion, and invasion of alien plants, are of particular concern as the consequences of such disruptions are largely unknown (Johnson 2004). This concern is well founded, especially given the recent suggestion by Vamosi et al. (2006) that plants in diversity hotspots may be more prone to pollination limitation and face higher extinction risks in the face of habitat destruction than those in less diverse areas.

There is still a paucity of data on the effects of habitat change on pollinators in the CFR. Pollinator assemblages and seed set showed variable responses to habitat fragmentation in a Renosterveld study by Donaldson et al. (2002). In the Namaqualand succulent Karoo region, Colville et al. (2002) found that overgrazing disrupted monkey beetle (*Rutelinae*: *Hopliini*) assemblages, most likely through changes in vegetation. However, in the same area, another study found that annual variation had a greater effect on monkey beetle diversity than grazing regime, although some species were still affected (Mayer et al. 2006). Pauw (2007) found that the loss of a generalist pollinator, an oil collecting bee (*Redividae*), had cascading effects on the seed set of specialist oil producing plants, but not on generalist plants. These effects were more severe in natural remnants in an urban matrix than in a rural matrix. These examples illustrate that the effects of habitat destruction and fragmentation in the CFR are complex and

Box 1

The interplay between plant and pollinator communities in agricultural landscapes



[Sven Vrdoljak]

Plant and pollinator communities are highly interrelated and changes within either community will affect the other. Landuse impacts associated with agriculture can alter pollination processes through direct or indirect impacts on the diversity and abundance of flower-visiting insects (anthophiles). The disruption of pollination will affect seed set, which in turn feeds back to affect the diversity and abundance of flowering plants. Changes to ecosystem function may degrade the quality of important ecosystem services, such as pollination, provided by the biodiversity contained within agricultural land, leading to further impacts on agricultural production and rural livelihoods (adapted from Donaldson et al. 2002).

not easily predictable, making the task of effectively conserving these interactions a daunting prospect.

Although the conservation value of the remaining natural habitat in the CFR is generally acknowledged, surprisingly few studies have attempted to quantify biodiversity in remnants of natural, semi-natural and transformed habitat. In a neighbouring biome, Xeric Succulent Thicket, Fabricius et al. (2003) found that a diverse landuse mosaic promoted gamma diversity, of arthropods and reptiles, although these authors emphasised the importance of reserve areas rather than the contribution of agricultural land. In the CFR, Witt & Samways (2004) highlight the importance of habitat remnants for maintaining the diversity, which exists here in between highly-transformed, species-poor fruit orchards. Boonzaaier (2006) also showed the value of remnant habitats for the conservation of ants in human influenced, lowland areas. In an urban context, Pryke & Samways (2009) found that a botanical garden of indigenous plants had major conservation value as a refugium for invertebrates.

Pan trap surveys of flower visiting insects, along with vegetation surveys at four sites (one within the reserve, a recovering area on the reserve boundary and two habitat fragments outside the reserve) at Elandsberg Nature Reserve in 2004 and 2005 found that remnants embedded within agricultural land outside the reserve maintained similar species richness to sites within the reserve (Fig. 5). Furthermore, the percentage of species that were shared between any two sites was relatively low, < 40% for insects and < 23% for plants (see Table 9). The assemblage structure of plants and insects was also significantly different between sites. These results show that not only can remnants maintain biodiversity outside of formally protected areas, but may also complement the biodiversity of protected areas through the addition of species and habitat that may not occur within the limits of reserves. Therefore, habitats outside of reserve areas make a meaningful contribution to conservation in a global biodiversity hotspot. Successful biodiversity conservation in the CFR should not take a binary ‘reserves vs. agricultural’ approach, but rather consider the entire landscape as a heterogeneous, eco-agricultural system that should be managed accordingly.

Ants are an important component of CFR biodiversity, as they play a central role in seed dispersal of many Fynbos species (Bond & Slingsby 1984). By taking the seeds, which are equipped with a fatty tissue body (elaiosome) to reward the ants, underground, they remove them from potential fire exposure, as well as from rodent predation (Bond & Slingsby 1984). Sheltered at an appropriate depth underground, the seeds can then germinate after a fire. In this way, ants contribute considerably to the regeneration of natural vegetation (Bond & Slingsby 1984, Christian 2001). The Argentine

Table 9: Comparisons of plants and flower visiting insect assemblages in, remnant (F1, F2), protected (R) and transformed (T) habitats at Elandsberg Nature Reserve (Alluvium Sand Fynbos)

Elandskloofberge		**% shared species**			**Similarity (Jaccard)**			**ANOSIM**		
		F1	**T**	**R**	**F1**	**T**	**R**	**F1**	**T**	**R**
Insects	**T**	38.13			0.616			1.00*		
	R	35.42	33.81		0.548	0.511		1.00*	1.00*	
	F2	34.03	35.25	35.42	0.516	0.544	0.548	0.963*	1.00*	0.963*
Plants	**T**	12.77			0.146			0.796**		
	R	18.18	10.47		0.222	0.117		1.00**	0.889**	
	F2	17.27	11.83	22.14	0.209	0.134	0.284	0.963**	0.759**	0.963**
	F2	17.27	11.83	22.14	0.209	0.134	0.284	0.963**	0.759**	0.963**

Figures represent the total percentage of species shared between each category, Jaccard's index of similarity based on species occurrences in each category and R values for a pairwise Analysis of Similarity (ANOSIM) of presence-absence data for each category.
Significance for ANOSIM are indicated as *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

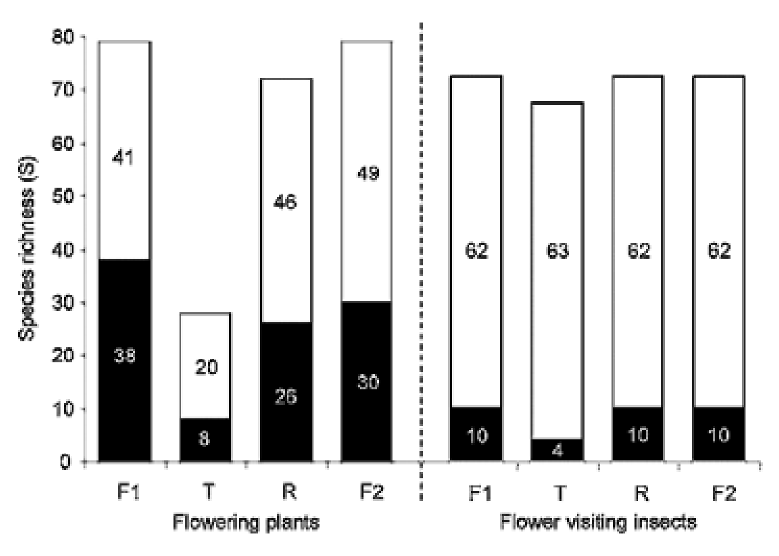


Fig. 5: Observed species-richness of flowering plants and flower visiting insects in two remnants of natural habitat (Alluvium Sand Fynbos) (F1; F2), as well as protected (R) and transformed (T) habitats at Elandsberg Nature Reserve. The black portion represents the number of species unique to that particular site, and the white portion those species shared with other sites.

Ant (*Linepithema humile*), an invasive species introduced to some areas of the Western Cape, does remove the seeds but at a much slower rate, thus hindering the regeneration of natural vegetation areas where Argentine ants are present (Bond & Slingsby 1984, Christian 2001).

Ant communities were investigated in a range of untransformed and transformed habitats (Boonzaier 2006) at Elandsberg and Riverlands, and a range of other sites across the Hottentots Holland Mountains. In spring, ant species richness estimates did not differ significantly between Riverlands (untransformed) and Pella (transformed), however, ant assemblage structure (taking into account the actual species identity and abundance) differed significantly (Fig. 6). The transformed and untransformed area shared 55.3% of ant species. At Elandsberg, the transformed site actually had significantly higher species richness than the reserve (Fig. 6), but no significant difference between assemblage structures could be found. Forty eight percent (47.6%) of ant species were shared between the Elandsberg transformed and untransformed area. A possible reason for lower species richness in the reserve site could be due to the overwhelming abundance of the Pugnacious Ant *Anoplolepis steingroeveri*, which may have, due to its dominance, excluded other ant species. A seasonal investigation of ant species richness and abundance at Elandsberg revealed that species richness is almost identical between Elandsberg Reserve and a transformed area surrounding the reserve (Table 10). Significant differences in species richness estimates and assemblage structure were however found in Stellenbosch and Grabouw. The significantly lower species richness in the transformed sites compared to the reserve sites of Grabouw and Stellenbosch may be due to underlying environmental factors such as soil (in particular the concentration of soil nutrients) and vegetation variables, which were significantly different between transformed and untransformed pairs in the Grabouw and Stellenbosch area. No significant differences in environmental variables were found for the Elandsberg, Riverlands/Pella or Somerset West Regions. Whether the differences in environmental variables are due to transformation or natural heterogeneity is not entirely clear. There was no significant difference in species richness estimates or assemblage structure between transformed and untransformed areas in the Somerset West Region. This

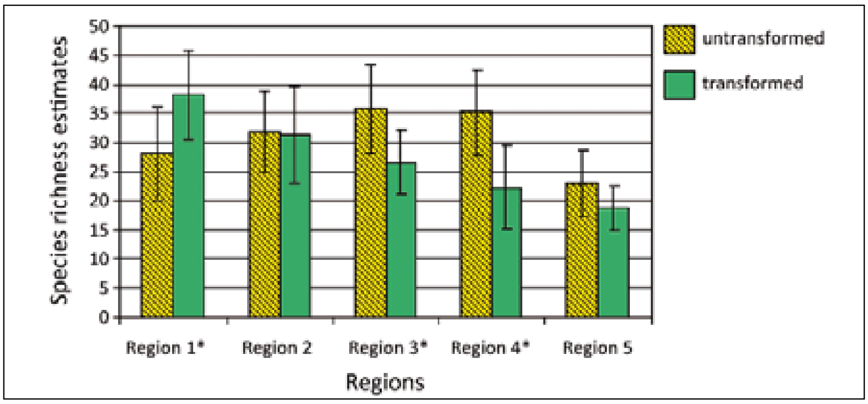


Fig. 6: Total ant species richness estimates (Jackknife 2 ± standard deviation as calculated by Estimates), using pitfall trapping, from paired untransformed (nature reserve) and transformed (remaining patches of veld surrounded by agriculture and/or invasive alien vegetation) areas in five regions in the Cape Floristic Region across the Western Cape. Five sites with 10 pitfall traps each were used in each area. Trapping was conducted in spring over 5 days. Region 1 = Elandsberg (Alluvium Sand Fynbos), Region 2 = Riverlands (Atlantis Sand Fynbos), Region 3 = Stellenbosch, Region 4 = Grabouw and Region 5 = Somerset West. * = significant differences at the 0.05 level.

Table 10: Total species richness estimates (Jackknife 2 ± standard deviation as calculated by EstimateS 7.5, Colwell 2005) of ants in the Elandsberg Reserve (Alluvium Sand Fynbos) and the transformed area surrounding the reserve

	Reserve	Transformed
Feb	37.27 ± 9.18	35.5± 6.59
June	23.39 ± 7.09	26.13 ± 6.59
Oct *	28.52 ±8.09	39.45 ± 9.53

Ten grids of 10 pitfalls each were used, five in the reserve and five in the transformed area. Sampling was conducted for 5 days per season.
* indicates significant differences between the reserve and transformed area at the 0.05 level.

is likely due to both transformed and untransformed sites being heavily invaded by the Argentine ant. The Argentine ant was also found in the transformed sites of the Grabouw and Stellenbosch Region, but was absent from the Elandsberg and Riverlands regions. The invasion of the Argentine Ant (which may be facilitated by transformations occurring in the Western Cape lowlands, Luruli 2007) and the resulting impact on indigenous ant communities (through, for example, the removal of food resources) is of greater importance than habitat transformation per se. Why the Argentine ant does not occur at Elandsberg and Riverlands is not clear, although it might be due to drier hotter climates at these sites in comparison to other sites sampled. Ants do not seem to be greatly affected by habitat transformation occurring near the reserves at Elandsberg and Riverlands, however the same cannot be said for all reserves and surrounding areas. Across all regions no noteworthy or sensitive species were lost due to transformation. However, the considerable transformation of the Western Cape lowlands overall may have already resulted in the loss of very sensitive species. The intensity of the transformation and in particular the invasion of the Argentine ant appears to reduce the ability of transformed landscapes to sustain current ant assemblages.

Effect of fragment size and landscape configuration on bird assemblages

Birds fulfil essential roles in ecosystems, among them seed dispersal and pollination (e.g. Garcia & Chacoff 2007). Previous studies conducted in the Cape Lowland region (Cameron 1999, Randrianasolo 2003) have shown that bird species richness decreases with fragment size. Similar findings are reported from a range of different habitats across the world (e.g. Santos et al. 2002, Castelletta et al. 2005, Watson et al. 2005, Johnson & Igl 2001). Bird assemblages and feeding guild composition was observed to vary considerably between habitat fragments (Fox & Hockey 2007), even on a local scale. In this study we aimed, on a bioregional scale, to identify the key factors underlying the responses to fragmentation of bird assemblages in Renosterveld, and how individual species and feeding guilds respond to fragmentation effects.

Species richness and species diversity of birds decreased with decreasing fragment size in the West Coast and East Coast Renosterveld Bioregion (Fig. 7). Species richness in larger fragments was higher in the west coast region, while in smaller fragments, species richness and diversity was similar in both regions. However, assemblage shifts occurred at greater fragment size in the West Coast Region than in the East Coast Region (50 ha compared to 20 ha, Kieck 2008). Although response pattern varied between the two regions, frugivorous species, as well as raptors and nectarivorous species were most affected by amount of habitat available and habitat distribution in the landscape.

Species richness and diversity reflect the presence and abundance of species in a habitat, and studies indicate that species occupancy of remnants in a landscape decreases as habitats become more fragmented (e.g. Trzcinski et al. 1999, Urban & Keitt 2001). It has been suggested that, below 20% of remaining habitat, fragment occupancy and population persistence may decline (Ford et al. 2001, Fahrig 2002, 2003, Ewers & Didham 2006). As species sensitive to habitat fragmentation are the first to be lost from an assemblage, Kieck (2008) suggests that generalist, or common species might be necessary to maintain ecological function, as they are often less affected by habitat fragmentation (Ewers & Didham 2006), and might be able to perform ecological roles specialists would otherwise have performed (Mennechez & Clergeau 2006).

We therefore set out to determine whether habitat characteristics, fragment size or landscape configuration determines the occupancy and relative abundance of common bird species in natural vegetation remnants in two different bioregions, using generalised linear models and ZIP models (Kieck 2008). Reflecting the results for species richness and diversity, species occupancy in the West Coast Renosterveld Bioregion was more influenced by fragment size, while in the East Coast Renosterveld Bioregion, amount of habitat available was more important (Table 11). Species abundances were determined by a mixture of landscape configuration, remnant isolation, and habitat type. Overall, fragment size was most important in influencing occupancy and abundance of common bird species (Kieck 2008).

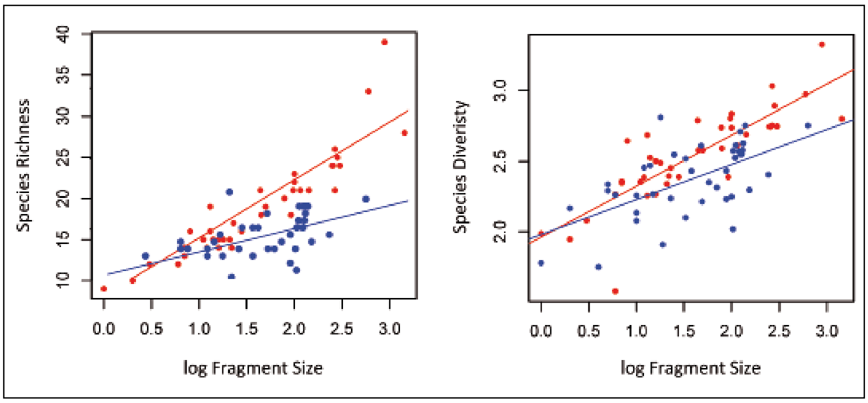


Fig. 7: Bird species richness and Shannon diversity index in relation to logarithm of fragment size in the West Coast (WCRB) (species richness: *Adj* R^2 = 0.8339, p = 0.000, species diversity: *Adj* R^2 = 0.6835, p = 0.000) and East Coast Renosterveld bioregions (ECRB) (species richness: *Adj* R^2 = 0.0.3317, p = 0.000, species diversity: *Adj* R^2 = 0.348, p = 0.000). Blue points represent ECRB fragment data; red points WCRB fragment data. Data from Kieck (2008).

Table 11: Predictors of species occupancy in East Coast (ECRB) and West Coast (WCRB) Renosterveld Bioregion as predicted by generalised linear models (adapted from Kieck 2008)

	Predictor	
Species	**ECRB**	**WCRB**
Speckled Mousebird	Habitat, landscape	Size
Cape Bulbul	Shrubcover	Size
Cape Grassbird	Size	Size
Bar-throated Apalis	Landscape, habitat	Size
Malachite Sunbird	Isolation	none
Karoo Scrub-robin	Habitat	none
Cape Bunting	Size	n.p.
Cape White-eye	n.p.	Size
Grey-backed Cisticola	none	Habitat
African Stonechat	none	Isolation
Cape Spurfowl	n.p.	Size

Size = fragment area (ha); Isolation = nearest neighbour distance (m); Landscape = amount of habitat within 5,000 m from sampling points; Habitat = Habitat variables [Grass cover, Shrub cover and Ground cover (%), Grass height and Shrub height - Average (cm)]. None = none of the factors tested had an influence on occupancy, n.p. = species not present in the region.

Small mammals

Small mammals are an important part of ecosystems (Kerley 1992). They are not only the prey basis for a number of birds and mammalian carnivore species, they are also known to be pollinators of plants, e.g. Proteaceae (Fleming & Nicolson 2002a, b, Wester et al. 2009), and seed dispersers (e.g. J. Midgley et al. 2002, Midgley & Anderson 2005). Their species richness, abundance and diversity has been shown to be strongly correlated with vegetation structure and complexity (Kerley 1992), making them sensitive to habitat changes. Therefore, small mammals have been used widely as indicators of species richness and diversity (Chase et al. 2000), and are regarded as useful indicators of change in arable landscapes (e.g. Tattersall et al. 2001, Sullivan & Sullivan 2006).

The response of small mammal species richness, abundance, and distribution to habitat transformation and fragmentation has been well documented in a range of different habitat types across the globe (e.g. Bolger et al. 1997, van Jaarsveld et al. 1998, Goodman & Rakotondravony 2000, Menzel et al. 1999, Schweiger et al. 2000). However, it is not only species richness and abundance that are influenced by the effects of fragmentation. The movement or dispersal ability of the species (e.g. Hopton & Choate 2002), and potentially their reproductive activity and productivity are also affected. This latter effect has, for example, been shown to be the case in birds (see e.g. Lloyd et al. 2005 or Hinam & Clair 2008). Small mammals might also change their behaviour, especially foraging behaviour, as a response to severe transformation (see e.g. Stokes et al. 2005). Small mammal species can react very differently to habitat transformation and these differences are likely determined by habitat preferences, spatial behaviour (e.g. territoriality) and mobility of individuals (Kozakiewicz et al. 1999, Michel et al. 2006, Mortelliti & Boitani 2009).

Therefore, whether viable populations can survive in a patchy, highly transformed landscape depends on a variety of factors, among them habitat quality in the remnants, fragment size and shape, distribution of patches within the landscape, connectivity between patches and suitability of the matrix. Generalist species, like *Rhabdomys pumilio*, might be able to survive this highly transformed landscape, as they are able to use the surrounding habitat (Todd et al. 2000, Tew et al. 2000, MacDonald et al. 2000), and are able to modulate their behaviour in response to environmental conditions (Krug 2002, Schradin 2005). Specialist species, which are dependent on certain plants or insects, are excluded from the surrounding habitat and might thus not be able to sustain viable populations in small and isolated fragments (Goodman & Rakotondravony 2000).

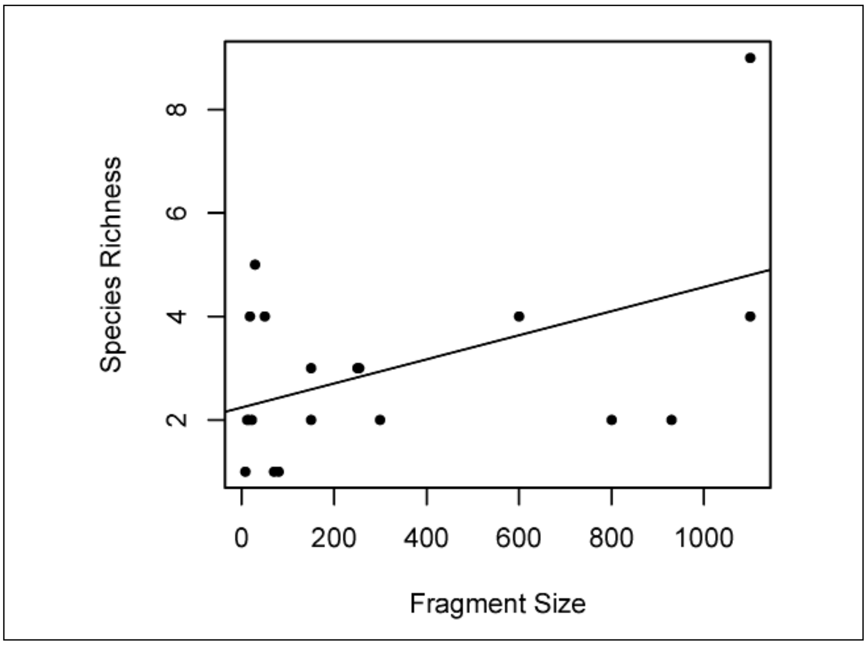


Fig. 8: Relationship between small mammal species richness and fragment size in 23 fragments investigated (Swartland Shale Renosterveld, Swartland Alluvium Fynbos, Atlantis Sand Fynbos and Langebaan Dune Strandveld). Data from Glatzle (2008), Krug (unpublished data), Moseley (2007) and Mugabe (2008). *Adj* $R^2 = 0.1932$, $p = 0.0300$

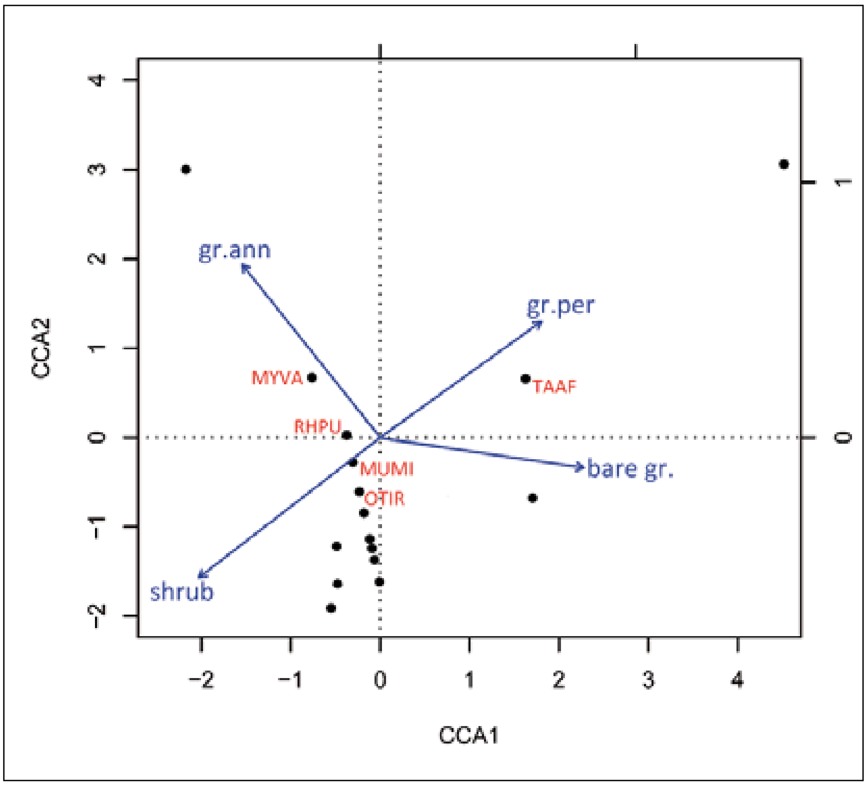


Fig. 9: Canonical Correspondence Analysis (CCA) of factors [percentage cover of annual grasses (gr.ann), perennial grasses (gr.per), shrubs (shrub) and bare ground (bare.gr)] determining abundance of most commonly trapped small mammal species [*Myosorex varius* (MYVA), *Mus minutoides* (MUMI), *Otomys irroratus* (OTIR), *Rhabdomys pumilio* (RHPU) and *Tatera afra* (TAAF)] in the remnants (Swartland Shale Renosterveld, Swartland Alluvium Fynbos, Atlantis Sand Fynbos and Langebaan Dune Strandveld) investigated (represented through solid dots). Axis 1 explains 60.4% of the variation, Axis 2 21.8%. Factors were reduced through a redundancy analysis (RDA). Source: Krug, unpublished data.

While the general biology and ecology of small mammals in South Africa has been investigated extensively (e.g. Keller & Schradin 2008, Kerley 1992, Schradin & Pillay 2006, Wirminghaus & Perrin 1993, Rambau et al. 2003), very little information is available on the effect of habitat transformation on small mammal communities in the CFR. The aim of the small mammal study was thus to determine how habitat fragmentation impacts on small mammal species assemblages, population ecology and reproductive biology of the species.

Of the more than 20 small mammal species that, based on distribution maps and habitat preferences, should occur in the Cape Lowlands, less than half were trapped between 2004 and 2008 (nine species). *Rhabdomys pumilio*, the Striped Mouse, was the most abundant of the species, and occurred in nearly every fragment investigated (Mugabe 2008, Glatzle 2009, Krug, unpublished data). *Mus minutoides* (Pygmy Mouse), *Myosorex varius* (Forest Shrew), *Otomys irrotatus* (Vlei Rat), and *Steatomys krebsii* (Krebs' Fat Mouse) were less frequently encountered, but still common. All other species were only caught occasionally.

Although Glatzle (2009) documented a positive relationship between fragment size and number of small mammal species for five sites in the Tygerberg region, an analysis of the whole dataset, covering 23 remnants, revealed only a weak relationship (*Adj* $R^2 = 0.1932$, $p = 0.03002$) between small mammal species richness and fragment size (Fig. 8). In fact, one of the largest fragments had the lowest species diversity of all remnants investigated, while two of the smallest remnants had exceptionally high diversity (Krug, unpublished data). Species diversity within a remnant is rather related to habitat diversity (Krug, unpublished data, Glatzle 2009), while presence or absence of species depends on vegetation unit and habitat structure (Fig. 9, Krug unpublished data).

Mugabe (2008) could further demonstrate the effect of habitat transformation on small mammal species assemblages. Both species richness and species abundance was significantly reduced in the transformed areas in comparison with the natural areas (Fig 10). At Riverlands, only two of the six species captured were

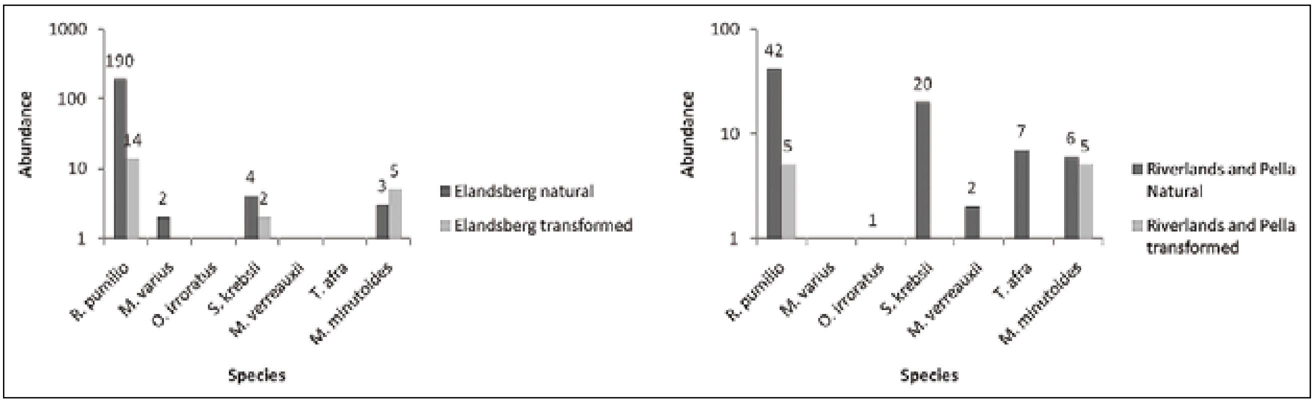


Fig. 10: Comparison of small mammal abundances in natural and transformed habitat at Elandsberg (Swartland Alluvium Fynbos) and Riverlands (Atlantis Sand Fynbos). Abundance axis is plotted on a log10 scale to allow for representation of vastly different abundances. Figure from Mugabe (2008).

found in the transformed habitat, while results were less pronounced at Elandsberg. At both sites, the species able to use the transformed areas were *Rhabdomys pumilio*, and *Mus minutoides*. However, use of the transformed land was seasonally dependent, and related to food availability (Mugabe 2008). The Striped Mouse (*R. pumilio*), which occurred in all fragments surveyed, regardless of size, and which is able to utilise transformed habitats, is nevertheless affected by habitat fragmentation. Reproductive activity of both sexes is reduced in the fragments (more so in females), compared to the mainlands (Table 12; Krug, unpublished data). The fact that female reproductive activity is more affected than male activity can be attributed to the fact that reproduction in females is coupled with higher energy demands, and thus linked to resource availability (Krug 2002).

Overall, because small mammals were captured in relatively low numbers the effects of habitat transformation and fragmentation on this taxon could not be determined with any degree of certainty in the Cape lowland region. However, the above studies across all other taxa show that, although biodiversity is negatively impacted by habitat transformation and fragmentation, small vegetation remnants contribute greatly to the biodiversity of the Cape Lowlands, and can play a meaningful role in conserving biodiversity in multi-use landscapes. The findings also underscore the importance of integrating these remnants into regional and fine-scale conservation and development plans.

Table 12: Proportion of reproductively active female and male *Rhabdomys pumilio* in large (mainlands) and corresponding smaller fragments in three vegetation types in September 2006 (Krug, unpublished data)

Vegetation	Sex	Mainland (n)	Fragment (n)
Renosterveld	female	0.78 (9)	0.18 (11)
	male	1 (2)	0.83 (6)
Sand Fynbos	female	1 (1)	0.5 (4)
	male	0.67 (3)	1 (4)
Strandveld	female	0.6 (5)	0.5 (2)
	male	1 (4)	0(0)

in brackets: total number of individuals captured

Negative secondary effects of fragmentation and isolation: edge effects and invasion by alien species

It is generally agreed (Fahrig 2003) that habitat reduction is by far the most severe effect of fragmentation. However, fragmentation can cause further size-independent problems, for example by increasing habitat edges. These edges are sites of habitat-matrix interactions, which could potentially be beneficial for some organisms, for example, as a source of additional food for small mammals in case of a grain field surrounding a Renosterveld patch. However, in most cases negative effects on the native ecosystem have been reported, caused by such impacts as fertiliser leakage, drift of pesticide sprays or high herbivory rates by livestock (Ries et al. 2004). Furthermore, many invasive species, especially grasses, thrive in the disturbed and nutrient enriched habitats along the edges (Sharma et al. 2010) and may gain a foothold there from which to invade the rest of the patch (Hobbs 2001).

Being aware of the severity and extent of edge effects has important implications for conservation planning. For example, large-scale edge effects would emphasise the need to maintain or create large, round patches in contrast to protecting a higher number of smaller and/or linear fragments (see the SLOSS-debate, Simberloff & Abele 1982, Quinn & Harrison 1988). In addition, understanding the various causes for any observed edge effects is essential to recommend counter measures.

To contribute to the conservation planning strategy for the Cape lowlands we chose to study edge effects in Swartland Shale Renosterveld on a number of different fragments using transects located at increasing distances from the edge of a fragment. We found that negative edge effects

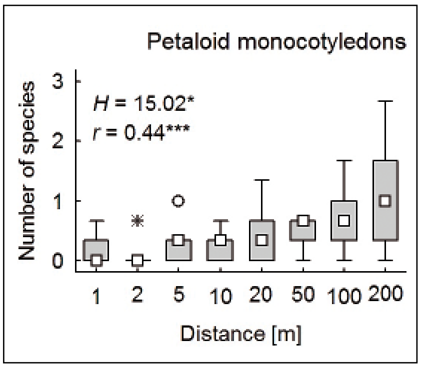


Fig. 11: Species richness of petaloid monocotyledons (bulbs etc.) from the edge towards the core of a Renosterveld vegetation remnant (*H* = Kruskal-Wallis ANOVA by ranks, *r* = Spearman Rank order correlation). Source: Horn et al. (under review).

appear to be quite severe and potentially extend to over 200 m for some taxa, as in the case of the floristically diverse and characteristic petaloid monocots (bulbs) (see Fig. 11), while most of the common woody species were quite unaffected (Horn et al., under review). Since the distance of 200 m for the bulbs far exceeds any reported for abiotic edge effects in the literature (Ries et al. 2004), we suspect biotic factors such as excessive herbivory and seed predation or perhaps pollinator limitations to be the cause. However, all of the sites in this study had been partially or wholly subjected to crop farming at some time in the past (> 50 years ago). It is therefore possible that apart from active edge effects the observed gradients in plant cover and species richness could also have been affected by soil changes associated with crop farming. In addition, species vary considerably in their dispersal abilities and the recolonisation of previously-ploughed areas from neighbouring, untransformed remnants is likely to vary between different taxa.

To study the relative effects of different soil nitrogen levels on alien grass invasion and indigenous vegetation, respectively and in combination, we combined field data with a greenhouse experiment. During a field study on Renosterveld sites down-slope of active fields or vineyards we collected data on soil nitrogen levels and plant biomass for alien grasses and indigenous plants in relation to the distance from the edge of the fragment. In conjunction with field observations, we conducted a greenhouse experiment growing Common Wild Oat (*Avena fatua*), an abundant invasive annual grass in this region, and three Renosterveld species from different functional groups under a range of soil nitrogen levels (Sharma et al. 2010).

In the field, we found significant decreases in soil nitrogen and cover of common wild oat from the edges to the interior of the Renosterveld patches. These gradients were significantly and positively correlated and reached about 40 m into the fragment. Consistently, the results of the greenhouse experiment revealed that the alien grass increased significantly in biomass when nitrogen was added, whereas the indigenous species did not. Furthermore, alien grass competition significantly influenced performance of an annual forb and an indigenous grass, but did not affect a geophyte. These results suggest that the conservation of the different functional groups requires a range of management approaches (Sharma et al. 2010).

If we assume that the detected gradients were mainly caused by active edge effects, then we recommend that patches larger than 400 m in diameter should receive highest conservation priority and that a minimum width of over 80 m is necessary to exceed the impact of alien grasses, if nutrient run-off from adjacent fields cannot be avoided. A replication of our study and possibly the validation of our findings in other areas would be extremely valuable to create a solid foundation for local conservation planning, although the selection of suitable sites is severely limited by site availability. We also recommend that the effect of soil parameters other than nitrogen should be determined. Furthermore, other potentially effective factors such as edge-related increased herbivory or decreased pollination rates need to be studied to prepare management recommendations for smaller, but important fragments.

5.3 Processes disrupted

Changes in seed dispersal and pollination processes

Loss of biodiversity and change of ecological communities irrevocably leads to disruption of ecological processes. Processes that are likely to be affected are seed dispersal and pollination by biotic agents, and the ecological disturbance regime of the vegetation, especially fire regime.

Previous studies on habitat fragmentation suggest that processes such as pollination and seed dispersal are particularly affected by habitat fragmentation (e.g. Aguilar et al. 2006, Donaldson et al. 2002). In our studies, we documented the impact of habitat transformation and fragmentation on pollination and seed dispersal processes. Vrdoljak (in prep.) tested the effect of nine habitat variables related to vegetation on pollinator assemblages found in different remnants at the Elandsberg Observatory (S32). Of these, as revealed by redundancy analysis, plant species composition, flower cover, plant species richness and average vegetation height were the most influential variables collectively explaining 51% of the total variation in pollinators, with flower cover being most important. This suggests that availability of resources and the structure and composition of the vegetation within habitat remnants play an important role in determining pollinator assemblages in these remnants.

Changes in ant communities, as observed by Boonzaier (2007), for example, could lead to a reduction in seed dispersal rates of selected species. Also, Kieck (2008), in his study on bird communities in Renosterveld, observed that frugivorous (i.e. seed dispersers) and nectarivorous (i.e. pollinators) bird species are particularly affected by habitat fragmentation. The changes observed in insect and bird communities are indeed reflected in the changes in plant functional type representation in remnants. A reduction in fragment size leads to a decrease in plant species richness and plant functional type richness (Kongor 2009). An examination of plant functional types revealed dispersal, pollination, and breeding mode as the traits most sensitive to habitat fragmentation. Species disappearing from small fragments include those with short-distance dispersed seeds, those pollinated by only very few insect species, and both annual and perennial re-seeding species.

The first two trait syndromes affect the ability of a species to colonise a suitable remnant, while the third limits the ability of the species to re-establish after disturbance (e.g. fire).

In short-distance dispersed species, the rate of re-colonisation from nearby patches is greatly reduced due to their poor dispersal ability (Bond et al. 1988, Bond 1994). For dioecious species, habitat fragmentation may lead to the separation of the sexes and consequently the absence of an effective population size. Thus, the establishment of a population of such species will become virtually impossible since both sexes are needed. Besides, smaller populations are more prone to higher extinction risks due to environmental, demographic, or genetic stochasticity (Franklin 1980, Shaffer 1981, Lindenmayer & Fischer 2006).

Small plant population sizes in smaller fragments can also reduce the likelihood of pollination, as these small populations are often less attractive to pollinators (Morgan 1999, Pauw 2004). Such small populations are often made up of closely related individuals, which lead to an increased likelihood of the loss of genetic diversity and inbreeding depression (Ellstrand & Elam 1993, Young et al. 1996, Matthies et al. 2004, Bruna & Oli 2005).

For species with highly specialised pollination systems, plant-pollinator interactions may be disrupted due to habitat fragmentation with potential ramifications for genetic diversity. For example, pollinators may visit flowers less frequently, leading to reduced fecundity and low seed set (Bond 1994, Donaldson et al. 2002, Bruna & Oli 2005, Ward & Johnson 2005, Aguilar et al. 2006, Lawson et al. 2008). However, as suggested by Donaldson et al. (2002) and Vrdoljak (in prep.), other factors such habitat and resources available for pollinators in habitat remnants play a role in structuring pollinator assemblages. Although it has been demonstrated that fragmentation has considerable negative effects on pollination service and seed set, responses by both pollinators and plants are species-specific, leading to complex responses that are difficult to generalise.

Impact on genetic exchange and genetic diversity of selected species

Changes in pollinator and seed disperser communities, as well as restricted movement of pollinators or dispersers between remnants, can have a negative effect on genetic exchange between populations, and thus impact on genetic diversity (Honnay & Jacquemyn 2007). Molecular techniques and analyses are important tools to study genetic variation in species, to set conservation goals and ensure evolutionary processes (Hedrick & Miller 1992). We argue that the fragmentation within the Renosterveld system could have a negative effect on genetic variation of plant species. Thus fragmentation reduces the potential of Renosterveld species to adapt to future environmental changes and evolutionary processes.

Preliminary results of a landscape study of two closely related annual plant species of the *Scrophulariaceae* family indicated that genetic differentiation between isolated plant populations depends on the rarity of the plant species (Heelemann et al., in prep.). Widespread *Hemimeris racemosa* revealed a higher level of genetic diversity than the more rare *Nemesia barbata*. In contrast, the latter species shows a stronger genetic differentiation between fragmented populations, than *H. racemosa*. Earlier research in the region, although in a different vegetation type, showed similar isolation effects within the *Proteaceae* family (Reisch et al. 2009).

Fragmentation is known to affect both genetic variation within and between populations. Lower levels of genetic variation within and a stronger genetic differentiation between populations can be expected for small and isolated populations in fragmented landscapes. However, in the case of *H. racemosa* and *N. barbata*, genetic variation was not significantly reduced in small and isolated populations compared to larger and less isolated ones. Furthermore, in both species genetic differentiation between small and isolated populations was comparable to genetic differentiation between larger and less isolated ones. Therefore, fragmentation seems not to affect genetic variation within and between *H. racemosa* and *N. barbata*. Although no fragmentation effect was detected for the above species, further habitat loss could reduce the genetic variability of species and needs to be avoided at all costs.

We also determined the effect of habitat fragmentation on dispersal and genetic patterns of a small rodent, *Rhabdomys pumilio* (Striped Mouse). *Rhabdomys pumilio* is a medium-sized (30–70 g) rodent of the family *Muridae* (Jackson & Bernard 2001, Schradin 2005). It is a diurnal, widespread African endemic and inhabits diverse types of habitats, e.g. forests, grasslands and deserts, of southern Africa (Kingdon 1974, Krug 2002, Schradin & Pillay 2006, Rambau et al. 2003, Schradin 2005). *R. pumilio* has been frequently documented as the dominant species of small mammal communities in the Western Cape lowlands (Krug unpublished data, Glatzle 2009). Moreover, its occurrence is also documented for Renosterveld (Rambau et al. 2003). Home range sizes of *R. pumilio* strongly vary in relation to rainfall and thus food availability (Krug 2002). Also, litter size depends on the availability and quality of food (Jackson & Bernard 2001) and as a result, the abundances of *R. pumilio* strongly fluctuate over seasons (Mugabe 2008, Krug, unpublished data).

Between 2005 and 2008, we sampled 71 specimens of *R. pumilio* for genetic analysis in 13 different Renosterveld fragments (Rösner, unpublished data). All study sites were isolated Renosterveld fragments with a maximum of 560 km distance between two sites. The fragments varied in size, ranging from 29 ha to 3,600 ha (Table 13). Some fragments comprised two different sites due to different local property names. Therefore all genetic samples were pooled in one population revealing a total of 13 local populations (Table 14). The amplification of the mitochondrial DNA sequences of the D-loop region was carried out with primers L15997 and H16401 (for details, see: Stacy et al. 1997, Meyer et al. 2006) and revealed fragments of 332 base pairs in length.

The 13 populations of *R. pumilio* showed a significant genetic differentiation ($p = 0.02$). However, the overall FST value of 0.08 was rather low and therefore the genetic differentiation moderate. Following the AMOVA calculation

Table 13: List of Renosterveld fragments and specimen samples of the Striped Mouse *Rhabdomys pumilio*

Renosterveld Fragment name	size [ha]	number of specimens sampled (sequenced)	list of haplotypes	rel. haplotype
Bottelary Hills	18.00	4	16, 21, 22, 23	1.0
Dorstberg	250.00	3	13, 16, 17	1.0
De Rust	150.00	2	6, 14	1.0
Elandsberg	3600.00	6	1, 2, 9, 10, 25	0.83
Elandsberg-SLK	n.a.	1	15	1.0
JN Briers-Louw	29.00	3	3, 13, 14	1.0
Koeberg	150.00	9	2, 3, 6, 8, 18	0.56
Kanonkop	150.00	9	3, 6, 11, 12, 19	0.56
Moerasfontein	600.00	6	2, 12, 26	0.5
Pela	600.00	5	2, 6, 15	0.6
Riverlands	1100.00	1	6	1.0
Rocherpan	600.00	5	2, 3, 13	0.6
Tygerberg	600.00	10	1, 3, 5, 24	0.4
Tygerberg Hills	254.00	2	3, 20	1.0
Van Riebeekshof	600.00	5	1, 2, 3, 4, 7	1.0
Summary	**Ø = 621.5**	**∑ = 71**	**# haplotypes = 26**	**Ø = 0.8**

Table 14: Analysis of molecular variance (AMOVA, Excoffier et al. 1992) of 71 *Rhabdomys pumilio* among 13 different populations in Renosterveld fragments, South Africa. Source: S. Rösner (Philipps University Marburg, unpublished data)

Source of variation	d.f.	Sum of squares	Variance of components	Percentage of variation	FST	P
Among populations	12	22.72	0.11	7.8	0.08	0.02
Within populations	58	75.33	1.30	92.2		
Total	70	98.05	1.41			

(Excoffier et al. 1992), the highest genetic differentiation was detected within populations (92.2%), whereas the differentiation among populations was rather low (7.8%, Table 14). The latter is the first indication for gene flow among the populations of *R. pumilio* in Renosterveld fragments. Furthermore, we found no significant genetic differences among populations separated by distances > 500 km. Further analyses revealed 26 different haplotypes, ranging from two to six haplotypes per population. We found no clear spatial geographic structure in terms of regionally clustered haplotypes (Fig. 12) even though the AMOVA documented a significant genetic differentiation among all populations.

In conclusion, our results revealed a moderate but significant genetic differentiation among the populations of *R. pumilio* in Renosterveld fragments. Moreover, the distribution of haplotypes was not clustered by populations. These findings suggest recent gene flow among isolated populations of *R. pumilio*. Either *R. pumilio* is a very good disperser and/or the agricultural matrix among the studied Renosterveld fragments is suitable habitat for this rodent, as shown by Mugabe (2008).

5.4 How to deal with fragmentation and its effects—management and intervention

Restoration

Restoration of degraded or semi-natural remnants or of transformed lands is one approach to increasing indigenous biodiversity in a region, and to improve connectivity in the landscape. Successful restoration depends on a number of factors, not least of which is the current state of transformation, and type and cover of alien invasive species.

Restoration under pine: Pine-afforested sites can be restored relatively easily via clearing. Preliminary results indicate that clearing of pine plantations and burning of cut biomass is a good restoration option (Heelemann et al., in prep.) which favours the recovery of indigenous plant species. Although soil properties changed at sites invaded by *Pinus* spp., making the soils more acidic, the soils still carry a viable seed bank of a sufficient number of indigenous species. Clear-cutting of pines on former Renosterveld areas enables the relatively rapid recovery of indigenous plant species.

Restoration of old agricultural fields: Fertiliser input and the ploughing of landscapes over decades irrevocably change soil properties and destroy much of the indigenous seed bank (Krug & Krug 2007). The old field seed bank has a generally low diversity (average species number is 30 of which 50% are exotics), in contrast to the seed bank in untransformed Renosterveld areas (average species number is 45 of which 30% are exotics) (Heelemann, in prep.). High soil nutrient levels, especially of nitrogen and phosphorous, lead to the establishment of alien grasses (Milton et al. 2004) or herbaceous weeds (Holmes 2008), while the changes in soil hydrology and electrical conductivity prevent the establishment of indigenous species

(Memiaghe 2008). Furthermore, because the soil seed bank is mostly destroyed, any recruitment of indigenous species must come from beyond the old field.

Restoration of old fields thus requires a multi-step approach. Before any indigenous species are re-introduced on the site (either through seeding or planting) the alien grass and weed cover must be removed and soil nutrient status and hydrology ameliorated. However, many old fields earmarked for restoration are adjacent to working agricultural fields, and thus subject to fertiliser, herbicide and pesticide drift, which may have a negative impact on restored plant and animal (particularly pollinator) communities on the site. Experience has shown that restoration success is short-lived if the restored site is not monitored regularly, and further intervention measures are not taken when necessary. Especially in Renosterveld, where near-complete transformation has taken place over a relatively long time period, is it nearly impossible to restore the original vegetation. In this vegetation unit, restoration efforts should therefore rather focus on a specific goal (such as restoration for game farming, or restoration for increasing the diversity of geophytes) than to aim at recreating a lost vegetation unit. Even then, fire and grazing or browsing by game, which are important disturbances in Renosterveld, are difficult to maintain in small remnants.

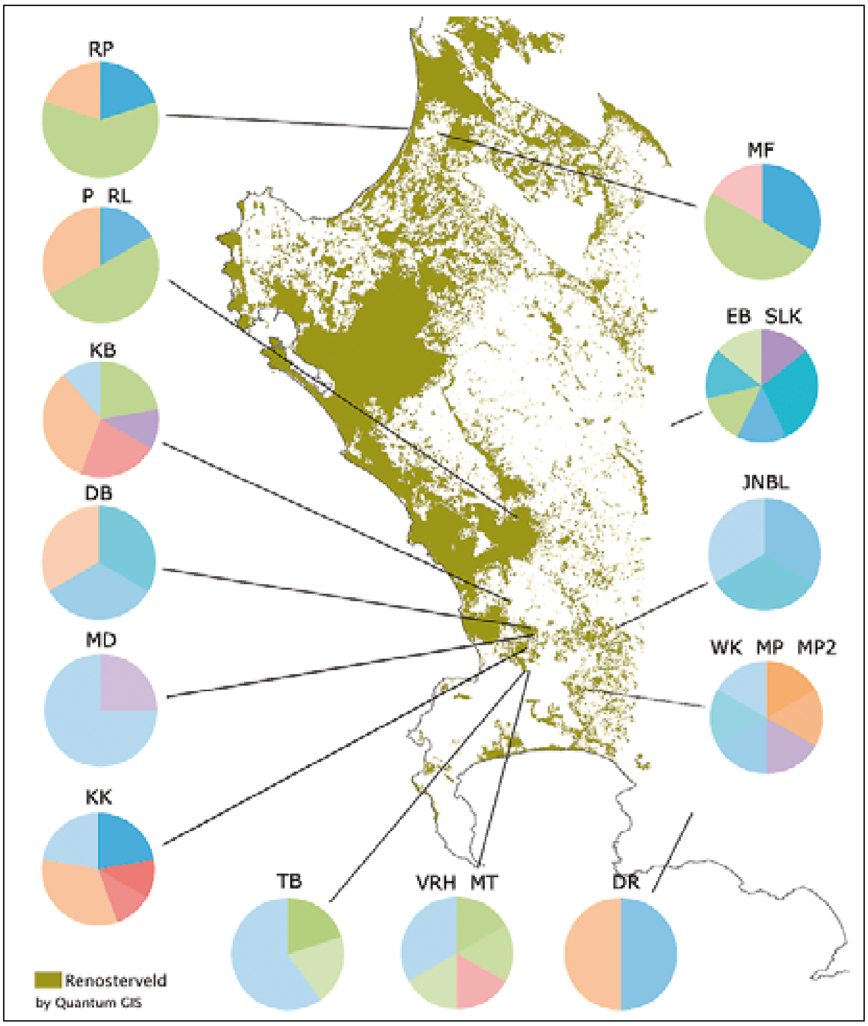


Fig. 12: Distribution of *Rhabdomys pumilio* haplotypes (n = 26) from 15 different Renosterveld fragments. For further information of fragment names and characters, see Table 13.

Based on the difficulties associated with restoring Renosterveld on old agricultural fields, conservation resources should rather be guided to activities that save the still existing Renosterveld fragments. Old fields are of minor restoration priority and could be used for novel approaches to restoration (Box 2) and projects with a development focus, such as nurseries for medicinal and horticultural plants and sanctuaries for stolen and threatened plants. If additional funds are available, pine plantations available for restoration should be identified and clear-cutting applied.

What are management options for vegetation remnants?

Alien control: BIOTA research specifically focussed on invasive alien grasses, which are particularly abundant in moist areas and in nutrient-enriched soils such as those where fertiliser has drifted from adjacent farm lands. Alien grasses are particularly difficult to control because they produce prolific amounts of seeds. These are stored in soil seed banks and the seeds are adapted for dispersal by large herbivores (Makady 2009). The best management solution is to avoid invasion in the first place by ensuring that a buffer is left between cultivated lands and natural vegetation, by minimising the chance of fertiliser drift in cultivated areas uphill from a Renosterveld or Fynbos patch and/or by ensuring that livestock that have grazed in areas infested by alien grasses in their seeding stages (in the Western Cape, this is normally between August and November) are not moved into natural veld camps during this time. Fires that are too frequent can also promote the spread of alien grasses. A common farming practice is to burn wheat stubble on cultivated lands and careful fire management is needed to ensure that the fires do not escape into surrounding lands. Finally, some work has been done on the removal of alien grasses on old fields as a component of restoration (Ruwanza et al., under review, and Article III.6.4). Herbicides (selective, pre-emergent systemic herbicides), fire, and mowing can temporarily reduce alien annual grasses but these treatments are expensive and their side effects are not fully understood.

Fire regime: Fire is an integral part of Fynbos and Renosterveld, but plays only a small role in Strandveld (Rebelo et al. 2006). Natural fire intervals depend on the age of the vegetation, fuel load, and environmental factors such as moisture content, season, temperature, time of day, wind, and

Box 2

A novel restoration approach to Renosterveld: letting birds do the dirty work

Photo 1: One of the bird perches set up at the experimental site at Tygerberg Nature Reserve. Bird droppings are collected on the net underneath the perch to determine the species and frequency of seeds excreted. Photo: S. Heelemann.

[Steffen Heelemann]

Abandoned agricultural fields on former Renosterved are a common feature in the Cape Lowlands of South Africa. Unfortunately, current restoration approaches were of low impact and therefore, novel approaches are needed for this area. Termitaria are a feature of Renosterveld vegetation and are characterised by broad-leaved shrubs with fleshy bird-dispersed fruits. Within the BIOTA framework we tested the effect of artificial bird perching structures and their potential to enhance fruit dispersal by birds in degraded Renosterveld plant communities in order to establish termitaria vegetation. The restoration experiment was performed at Tygerberg and Bottleray Hills and was compromised of perches and seed traps in abandoned agricultural fields. Results show an increased seed dispersal of seeds and species where perches were established. On average, 200 seeds of 12 species were found under each perch at a restoration site with nearby dense shrub vegetation. Only 20 seeds of 10 species per perch were found at a restoration site adjacent to sparse shrub vegetation. Unfortunately, germination and establishment of dispersed seeds appeared to be low and insufficient even in exotic grass-free sites. It is therefore questionable if further restoration efforts should be directed at old fields with their highly competitive exotic grass vegetation and altered soil conditions.

aspect (Rebelo et al. 2006). For Lowland Fynbos, fire intervals of 4–25 years (on average 7 years) are suggested (Brownlie & Mustart 1988). In Renosterveld, fire intervals should be shorter (2–10 years, Rebelo et al. 2006), although the interval length depends on the grazing intensity. The higher the grazing intensity, the longer the fire interval should be.

To ensure the survival of species, to aid regeneration of vegetation, and to obtain a mix of vegetation ages, a remnant should never be burned at once, but divided in to burn "blocks" (separated by fire breaks). In a very small remnant, this might only be two or three blocks while a large remnant can have as many fire management blocks as necessary. The division into burn blocks should be based on current vegetation structure, vegetation age and fire history. To ensure the survival of populations, each structural community and age class should be represented at least twice. When starting the fire management programme, old and senescent stands should be burned first. In Fynbos, stands of less than six years should not be burned, as plants have not reached maturity and set seeds, and not enough fuel has accumulated to maintain the fire.

The recommended burn season for both vegetation units is in the late summer (February–March) which is the seasons when fires would naturally have occurred in the past. Burning at any other time of the year will change the intensity and temperature of the fire, and might lead to a subsequent change in vegetation composition. In Renosterveld, spring fires lead to grass-dominated vegetation (Cowling et al. 1986).

Grazing/browsing: Large mammalian herbivores were an integral part of the Renosterveld ecosystem (Krug & Krug 2007, Rebelo et al. 2006), but were hunted to extinction or near-extinction in the 18th century. Smaller antelope species (Steenbok, Grey Rhebok, Cape Grysbok, and Common Duiker) are still present in many natural vegetation remnants, even small ones (C. Krug, pers. observation).

The re-introduction of large indigenous herbivores is only feasible in very large remnants, and needs to be done at the appropriate stocking rate of about 0.09 LSU/ha (Makady 2009). Species that can be considered for re-introduction include Eland (*Taurotragus oryx*), Red Hartebeest (*Alcephalus busephalus*), Cape Mountain Zebra (*Equus zebra zebra*), Black Rhinoceros (*Dicerus bicornis*) and Ostrich (*Struthio camelus australis*). The Quagga (*Equus quagga quagga*), was hunted to extinction, but can be substituted by Burchells' Zebra (*Equus burchelli*), which is a close relative. Bontebok (*Damaliscus dorcas dorcas*) could also be considered for re-introduction although this species is likely to have only occurred east of the Hottentots Holland Mountains (Radloff 2008).

Large herbivores not only impact on vegetation through grazing or browsing, but also through trampling and soil perturbation. Brush-cutting techniques are thus likely insufficient in mimicking herbivore action in Renosterveld or Strandveld, and often do not have the desired effects (M. Gregor, pers. communication). In Renosterveld, fire may be used as a substitute for grazing, but this is not appropriate for Strandveld vegetation units.

Box 3

Impact of alien invasive species on *Protea* population dynamics

[Juliano Cabral, Henning Nottebrock & Frank Schurr]

Habitat fragmentation imposes not only direct loss of natural habitat but also several negative consequences to the vegetation remnants (see Primack 2008). One of the most dramatic consequences is the disappearance of species due to a too small remnant area, which may not be able to sustain viable populations. To demonstrate this effect, we conducted a simple simulation experiment with *Leucadendron lanigerum* subsp. *lanigerum*. This plant is endemic to the western lowlands and is highly threatened by habitat fragmentation because its per-capita reproduction declines in small populations (Cabral & Schurr 2010). In addition, the habitat loss experienced by the subspecies is further aggravated by the wide-spread presence of alien species. In our experiment, we simulated the population dynamics of this plant within the habitat where it can potentially occur, mostly the western lowlands (G.F. Midgley et al. 2002). In order to show the effects of habitat loss that have already occurred due to both habitat fragmentation and alien species invasions, we simulated two scenarios: without and with past habitat loss (Rouget et al. 2003). Considering realistic parameters (Cabral & Schurr 2010), the simulation shows that without the past habitat loss, *L. lanigerum* subsp. *lanigerum* could be found over most of the potential range, whereas with past habitat loss it is mostly confined to the more pristine habitat remnants. Other species of Proteaceae may show similar sensitivity to habitat fragmentation: a study of 30 populations of *Protea repens* found a reduction of seed set per plant in small Proteaceae stands. This is likely to cause a decline of per-capita reproduction similar to the one found for *L. lanigerum* subsp. *lanigerum*.

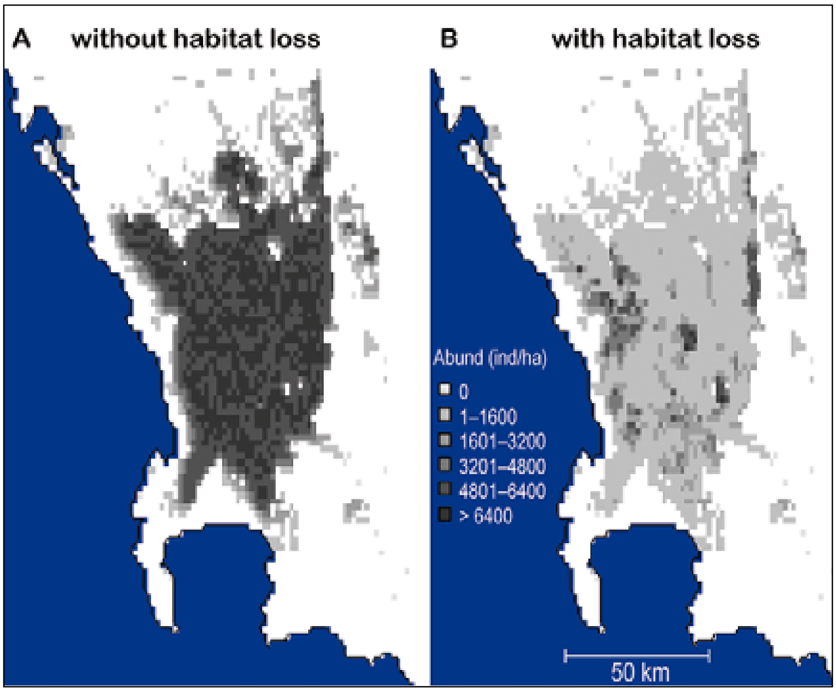


Fig. 14: Abundance distribution of *Leucadendron lanigerum* subsp. *lanigerum*, for simulation scenarios, (A) without and (B) with habitat loss. The presented abundance was averaged over 100 replicate simulations with the parameter values obtained by Cabral & Schurr (2009). The grey area indicates the suitable habitat where the species can occur according to bioclimatic envelopes (G.F. Midgley et al. 2002). Without habitat loss, the species occurs throughout the suitable habitat. With past habitat loss, the species shows high abundances only in the areas that have undergone little or low habitat loss. These remnant areas represent most of the areas where the species can still be found.

Here, brush-cutting is the main option to mimic the effects of large mammalian herbivory on the vegetation.

Conservation strategies

Aims

Conservation strategies in the Cape Lowlands should be aimed at 1) increasing the connectivity between remnants, through for example, the establishment of corridors and stepping stones, 2) appropriate management of the remnants themselves that takes into consideration natural disturbances and important ecological processes, and 3) clearing of alien invasive species and the restoration of semi-natural and transformed areas.

Corridors

Although the single most detrimental effect of habitat fragmentation is the reduction of habitat per se (Fahrig 2003), other aspects such as the isolation or connectivity between the remaining fragments also play an important role (Fischer & Lindenmayer 2007). Theoretically, fragments that are close to each other or effectively connected by functional corridors are likely to have higher rates of dispersal between them than unconnected fragments far apart from each other. This would prevent many of the negative

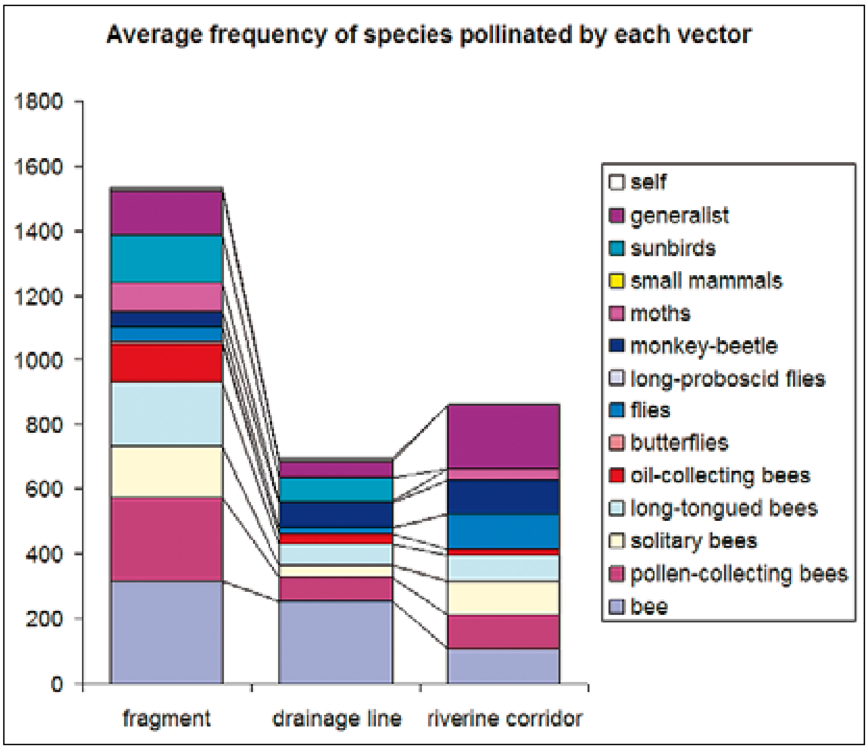


Fig. 13: Frequency distribution of plant species pollinated by different vectors in a Renosterveld fragment, drainage line and riverine corridor. Source: Horn (in prep.).

effects of fragmentation, such as local extinctions due to habitat fluctuations and genetic degradation associated with inbreeding (Lennartson 2002). However, connective corridors have not generally been accepted as functional (Beier & Noss 1998) and, more problematically, have been suspected to act as conduits for alien species invasion (Procheş et al. 2005). Box 3 illustrates the impacts of habitat loss and invasive alien species on population dynamics of Proteaceae.

In the heavily fragmented Swartland Shale Renosterveld of the West Coast Cape Lowlands, few broad connecting strips of natural vegetation remain. Most of those that do exist are narrow, less than 150 m wide, and all are more or less heavily infested by alien woody species, such as Australian acacias and eucalyptus species, and grasses. We set out to investigate the functionality of these corridors as habitat in their own right and, more critically, as movement corridors for plants and animals of the natural ecosystems. For this purpose, we collected information on the occurrence of species and their frequencies along transects within Renosterveld patches and along narrow drainage line corridors directly adjacent to the patches (< 50 m) as well as broad riverine corridors (100–150 m) with a special focus on the species rich and characteristic bulbous plants.

Our results indicated that species richness and individual species frequencies are considerably lower within the corridors, but that pollination syndromes among bulbous plants were generally similar to the larger habitat patches (Fig. 13; Horn et al., unpublished data). Exceptions were bird-dispersed and monkey-beetle pollinated plants, which were much rarer in corridors. Interestingly, the riverine corridor with the highest species richness was the one with the highest number of drainage line connections to the nearest large fragment.

We concluded that corridors in their current conditions could function as effective movement corridors for plants and a wide range of pollinating animals, albeit at a sub-optimal level. We believe that the control of alien vegetation as well as the limitation of fertiliser and pesticide influx would significantly improve the functionality of these corridors.

Regarding the potential negative effects of corridors as invasion conduits, we found no evidence of increased invasion rates within fragments near corridor connection points, though we did not specifically test this and thus, would recommend an investigation of this aspect in the future. Another vital step would be to test for actual pollinator activity and effective pollination rates to confirm the effectiveness of corridors for pollinator movement. Also, it would be important to establish whether bird pollinators would visit plants with bird-pollination syndromes planted along the corridors to see if corridors could increase their movement rates between fragments.

Box 4 describes the effects of certain improved conservation measures (reduced habitat loss, improved alien clearing) on *Leucadendron lanigerum* subsp. *lanigerum*, a broad-leaved shrub within the *Proteaceae* which has been shown to be negatively affected by habitat fragmentation. The results of the simulation show an increase in abundance the remnant populations, and highlight the possibility of connecting the three main remnant populations through corridors in order to increase gene flow between them.

Our research highlights the contribution of small remnants to the overall biodiversity of the Cape Lowlands, as well as the urgent need for the conservation and appropriate management in the region. As most of the surviving natural remnants within the Cape Lowlands are in private hands, and the area contributes considerably to the economy of the Western Cape (and South Africa), new approaches must be taken to conserve and protect some of the last remaining remnants of these unique vegetation units. Box 5 provides guiding principles for the management of eco-agricultural multi-use landscapes.

With the growth and success of the Biodiversity and Wine Initiative, as well as the CapeNature Stewardship Programme, provision of urgently needed scientific support to conservation managers, land owners and decision makers, and urgent conservation intervention where necessary, the Cape Lowland archipelago might stay afloat a while longer.

Box 4

Putting mitigating measures in place: the effect of reduced alien invasion and improved habitat connectivity on population dynamics of Proteaceae

[Juliano Cabral]

The presence of alien species in remnant vegetation worsens the loss of indigenous biodiversity due to their ability to outcompete native species. To assess the impact of current alien species infestation on the maintainance of the natural populations, we conducted a simulation experiment, which mimicked an improvement in conservation measures using *Leucadendron lanigerum* subsp. *lanigerum* as our case study species. We decreased the percentage of habitat loss, including the area infested by alien species, in the area where the species can still be found. The result showed that the remnant populations would increase slightly in comparison with current percentages of habitat loss. Through appropriate conservation planning, It would be also possible to successfully connect the three main remnant populations through corridors, thus assuring genetic flow between them.

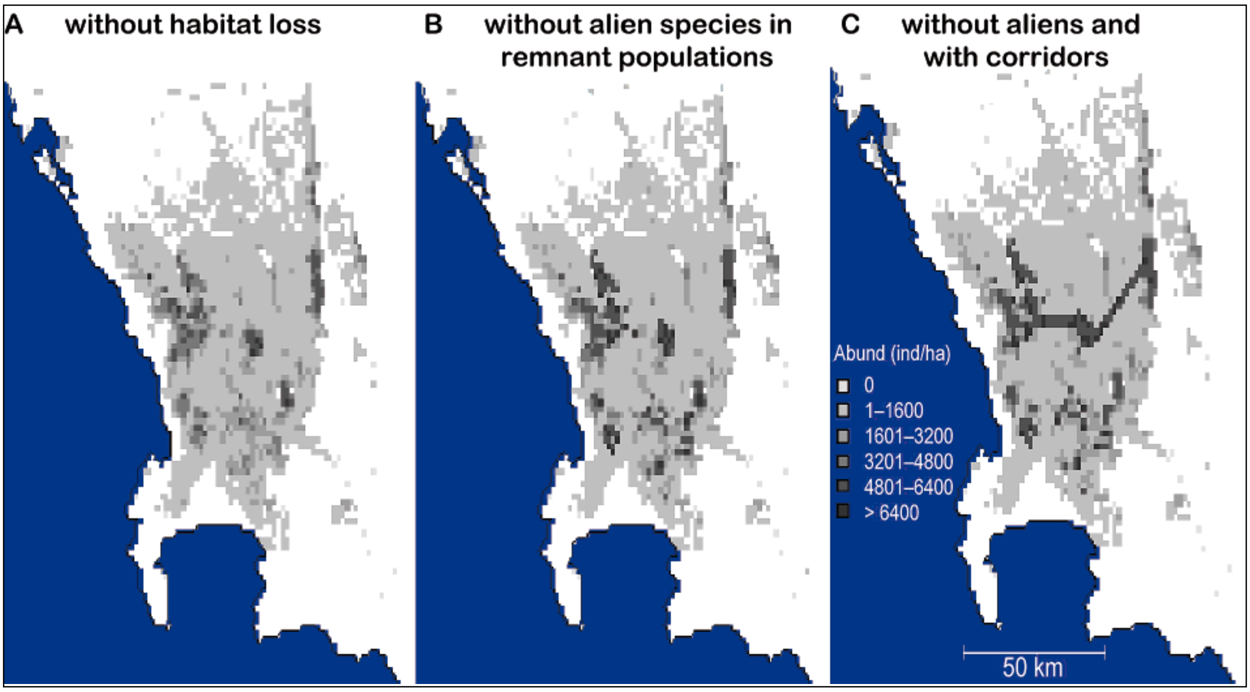


Fig. 15: Abundance distribution of the study case species, *Leucadendron lanigerum* subsp. *lanigerum*, for simulation scenarios, (A) with past habitat loss, (B) with past habitat loss but without alien infestation in the more pristine areas, and (C) without aliens but with corridors. The presented abundance was averaged over 100 replicate simulations with the parameter values obtained by Cabral & Schurr (2010). The grey area indicates the suitable habitat where the species can occur according to bioclimatic envelopes (G.F. Midgley et al. 2002). Corridors were added as 1.5 or 3 km wide stripes with 95% restored vegetation area among the three main extant populations (only 3 km shown in C). Note that without alien species present, *L. lanigerum* is able to maintain larger populations in the remnant habitat patches. Corridors (1.5–3 km wide) do not enhance population sizes, but are able to connect successfully the three main remnant populations (C).

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References

Aguilar, R., Ashworth, L., Galetto, L., Aizen, M.A. (2006): Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. – Ecology Letters **9**: 968–980.

Andren, H. (1994): Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. – Oikos **71**: 355–366.

Beier, P., Noss, R.F. (1998): Do habitat corridors provide connectivity? – Conservation Biology **12**: 1241–1252.

Bolger, D., Alberts, A., Sauvajot, R., Potenza, P., McCalvin, C., Tran, D., Mazzoni, S., Soule, M. (1997): Response of rodents to habitat fragmentation in coastal southern California. – Ecological Applications **7**: 552–563.

Bond, W.J. (1994): Do mutualisms matter? Assessing the impact of pollinator and disperser disruption on plant extinction. – Philosophical Transactions of the Royal Society of London Series B **344**: 83–90.

Bond, W.J., Slingsby, P. (1984): Collapse of an ant-plant mutualism: the argentine ant (*Iridomyrmex humilis*) and myrmecochorous Proteaceae. – Ecology **65**: 1031–1037.

Bond, W.J., Midgley, J, Vlok, J. (1988): When is an island not an island? Insular effects and their causes in fynbos shrublands. – Oecologia **77**: 515–521.

Box 5
Guiding principles for the management of ecoagricultural landscapes

[Sven Vrdoljak]

The need for conservation outside of protected areas has become widely recognised (Norris 2008). One means of addressing this challenge lies in conserving biodiversity through 'ecoagriculture'. This entails the creation of integrated conservation-agriculture landscapes (Scherr & McNeely 2008), based upon the inclusion of ecological principles into the design and management of multiuse landscapes for agricultural production and biodiversity conservation (Fischer et al. 2006, Samways 2007). Scherr & McNeely (2008) define ecoagricultural landscapes as mosaics of areas in natural habitat and areas under agricultural production. These mosaics are comprised of:

- 'natural' areas, managed to benefit agricultural livelihoods by providing critical elements for habitat and ecosystem services that cannot be provided by areas under production;
- agricultural production areas, configured and managed to provide a benign or beneficial matrix for wild biodiversity and ecosystem services while remaining profitable, productive and sustainable;
- institutional mechanisms coordinating synergies and tradeoffs between conservation and livelihood objectives at various scales (from farms to entire landscapes).

Spatial configuration of the natural and agricultural components of the landscape, as well as other structural elements such as human settlements and infrastructure are key landscape design issues, as is the management of these components. Samways (2007) elucidates six basic principles to form a framework for a synthetic management approach to conservation at the landscape level:

- maintain reserves (as large as possible);
- maintain as much quality habitat heterogeneity as possible (including the removal or suppression of invasive aliens);
- remove hard edges between natural remnants and disturbed habitat (softer boundaries between natural and trans formed land reduce edge effects and improve connectivity);
- introduce land sparing outside reserves (instigating conservation headlands, conservancies and other schemes to provide undisturbed/less disturbed habitat);
- simulate natural disturbance and processes through management (e.g. fire and grazing regimes);
- maintain corridors to connect patches of high quality habitat to allow movement and maintain evolutionary potential of the landscape

Linking these six principles is the metapopulation trio of large patch (habitat) size, good patch quality, and good connectivity between patches, which are essential to maintain healthy, viable populations of indigenous flora and fauna. At a much finer scale, a species approach can be overlaid, focused on the needs of particular species under threat. Successfully integrating these principles into conservation planning requires the engagement of conservation planners and stakeholders at various levels. The principles laid out above should not be prescriptive, but rather used to guide management and planning to exploit the conservation potential of agricultural landscapes.

Boonzaaier, C. (2006): Conservation in human-influenced areas: epigaeic arthropods in the Cape Floristic Region lowlands. – MSc. Thesis. Stellenbosch: Stellenbosch University.

Brownlie, S., Mustart, P.J. (1988): History of recent land–use and management implications. – In: Jarman, M.L. (ed.): A description of the fynbos biome project intensive study site at Pella. Foundation for Research Development Ecosystem Programmes Occasional Report No. 33. Pretoria: CSIR.

Bruna, E.M., Oli, M.K. (2005): Demographic effects of habitat fragmentation on a tropical herb: life table response experiments. – Ecology **86**: 1816–1824.

Cabral, J.S., Schurr, F.M. (2010): Estimating demographic models for the range dynamics of plant species. – Global Ecology and Biogeography **19**: 85–97.

C.A.P.E. Co-ordination Unit (2003): Natural vegetation remnants: ArcView 3.2 shapefiles. – Cape Town: Botanical Society of South Africa.

Cameron, A. (1999): The effects of fragmentation of Renosterveld vegetation on bird community composition. – MSc Thesis, University of Cape Town, South Africa.

Castelletta, M., Thiollay, J., Sodhi, N.S., (2005): The extreme forest fragmentation on the bird community of Singapore Island. – Biological Conservation **121:** 135–155.

Chase, K., Kristan, B., Lynam, J., Price, V., Rotenberry, T. (2000): Single species as indicators of species richness and composition in California coastal sage scrub birds and small mammals. – Conservation Biology **14**: 474–487.

Christian, C.E. (2001): Consequences of a biological invasion reveal the importance of mutualism for plant communities. – Nature **413**: 635–639.

Colville, J., Picker, M.D., Cowling, R.M. (2002): Species turnover of monkey beetles (Scarabaeidae: Hopliini) along environmental and disturbance gradients in the Namaqualand region of the succulent Karoo, South Africa. – Biodiversity and Conservation **11:** 243–264.

Colwell, R.K. (2005): EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5 User's Guide and application. – http://viceroy.eeb.uconn.edu/estimates [acc. 15.05.2010].

Cornelissen, J.H.C., Lavorel, S., Garnier, E., Díaz , S., Buchmann, N., Gurvich, D.E., Reich, P.B., Steege, H. ter, Morgan, H.D., Heijden, M.G.A. van der, Pausas, J.G., Poorter, H. (2003): A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. – Australian Journal of Botany **51**: 335–380.

Cowling, R., Bond, W. (1991): How small can reserves be? An empirical approach in Cape fynbos, South Africa. – Conservation Biology **58**: 243–256.

Cowling, R., Pierce, S., Moll, E. (1986): Conservation and utilisation of South Coast Renosterveld, an endangered South African vegetation type. – Biological Conservation **37**: 363–377.

Cowling, R.M., Pressey, R.L., Rouget, M., Lombard, A. T. (2003): A conservation plan for a global biodiversity hotspot - the Cape Floristic Region, South Africa. – Biological Conservation **112:** 191–216.

Debinski, D.M., Holt, R.D. (2000): A survey and overview of habitat fragmentation experiments. – Conservation Biology **14**: 342–355.

Desmet, P., Cowling, R. (2004): Using the species–area relationship to set baseline targets for conservation. – Ecology and Society **9**(2): 11. http://www.ecologyandsociety.org/vol9/iss2/art11/

Donaldson, J., Nanni, I., Zachariades, C., Kemper, J., Thompson, J.D. (2002): Effects of habitat fragmentation on pollinator diversity and plant reproductive success in Renosterveld shrublands of South Africa. – Conservation Biology **16:** 1267–1276.

Ellstrand, N.C., Elam, D.R. (1993): Population genetic consequences of small population size: implications for plant conservation. – Annual Review of Ecology and Systematics **24**: 217–242.

Excoffier, L., Smouse, P.E., Quattro, J.M. (1992): Analysis of molecular variance inferred from metric distances among DNA haplotypes: application to human mitochondrial DNA restriction data. – Genetics **131**: 479–491.

Ewers, R., Didham, R. (2006): Confounding factors in the detection of species responses to habitat fragmentation – Biological Reviews **81**: 117–142.

Fabricius, C., Burger, M., Hockey, P.A.R. (2003): Comparing biodiversity between protected areas and adjacent rangeland in xeric succulent thicket, South Africa: arthropods and reptiles. – Journal of Applied Ecology **40:** 392–403.

Fahrig, L. (2002): Effect of habitat fragmentation on the extinction threshold: a synthesis. – Ecological Applications **12:** 346–353.

Fahrig, L. (2003): Effects of habitat fragmentation on biodiversity. – Annual Review of Ecology, Evolution and Systematics **34**: 487–515.

Fairbanks, D.H.K., Hughes, C.J., Turpie, J.K. (2004): Potential impact of viticulture expansion on habitat types in the Cape Floristic Region, South Africa. – Biodiversity and Conservation **13:** 1075–1100.

Fischer, J., Lindenmayer, D.B. (2007): Landscape modification and habitat fragmentation: a synthesis. – Global Ecology and Biogeography **16**: 265–280.

Fleming, P.A., Nicolson, S.W. (2002a): Opportunistic breeding in the Cape spiny mouse. – African Zoology **37**: 101–105.

Fleming, P.A., Nicolson, S.W. (2002b): How important is the relationship between *Protea humiflora* (Proteaceae) and its non-flying mammal pollinators? – Oecologia **132**: 361–368.

Ford, H.A., Barrett, G.W., Saunders D.A., Recher, H.F. (2001): Why have birds in the woodlands of Southern Australia declined? – Biological Conservation **97:** 71–88.

Fox, S., Hockey, P.A.R. (2007): Impacts of a South African coastal golf estate on shrubland bird communities. – South African Journal of Science **103:** 27–34.

Franklin, I.R. (1980): Evolutionary changes in small populations. – In: Soulé, M.E., Wilcox, B.A. (eds): Conservation biology: an evolutionary–ecological perspective: 135–150. Sunderland: Sinauer Associates.

Garcia, D., Chacoff, N.P. (2007): Scale-dependent effects of habitat fragmentation on hawthorn pollination, frugivory, and seed predation. – Conservation Biology **21**: 400–411.

Glatzle, M. (2009): Habitat structure and small rodent diversity in the Renosterveld of South Africa. – Bachelor thesis. Marburg: Philipps University Marburg.

Goodman, S., Rakotondravony, D. (2000): The effects of forest fragmentation and isolation on insectivorous small mammals (Lipotyphla) on the central high plateau of Madagascar. – Journal of Zoology, London **250**: 193–200.

Hedrick, P.W., Miller, P.S. (1992): Conservation genetics: techniques and fundamentals. – Ecological Applications **2**: 30–46.

Hinam, H.L., Clair, C.C.S. (2008): High levels of habitat loss and fragmentation limit reproductive success by reducing home range size and provisioning rates of Northern saw-whet owls. – Biological Conservation **141**: 524–535.

Hobbs, R.J. (2001): Synergisms among habitat fragmentation, livestock grazing, and biotic invasions in southwestern Australia. – Conservation Biology **15**: 1522–1528.

Holmes, P. (2008): Optimal ground preparation treatments for restoring lowland Sand Fynbos vegetation on old fields. – South African Journal of Botany **74**: 33–40.

Holmes, P.M., Richardson, D.M. (1999): Protocols for restoration based on recruitment dynamics, community structure, and ecosystem function: perspectives from South African fynbos. – Restoration Ecology **7**: 215–230.

Honnay O., Jacquemyn H. (2007): Susceptibility of common and rare plant species to the genetic consequences of habitat fragmentation. – Conservation Biology **21:** 823–31.

Hopton, M., Choate, J. (2002): Effects of habitat fragmentation on movement of small mammals along a Kansas highway. – The Southwestern Naturalist **47**: 319–324.

Jaarsveld, A. van, Fergusson, J., Bredenkamp, G. (1998): The Groenvaly grassland fragmentation experiment: design and initiation. – Agriculture, Ecosystems & Environments **68**: 139–150.

Jackson, C., Bernard, R.T.F. (2001): Gender differences in the inhibitory effects of a reduction in ambient temperature and a reduction in food quantity on reproduction in the Southern African rodent, *Rhabdomys pumilio*. – Reproduction **122:** 385–395.

Johnson, D.H., Igl, L.D., (2001): Area requirements of grassland birds: a regional perspective. – The Auk **118:** 24–34.

Johnson, S.D. (2004): An overview of plant-pollinator relationships in southern Africa. – International Journal of Tropical Insect Science **24**: 45–54.

Jonas, Z., Rouget, M.B., Reyers, B., Mohamed, B., Rutherford, M.C., Mucina, L., Powrie, L.W. (2006): Vulnerability assessment of vegetation types. – In: Mucina, L., Rutherford, M.C. (eds.): The vegetation of South Africa, Lesotho, and Swaziland: 738–747. Pretoria: South African National Biodiversity Institute.

Keller, C., Schradin, C. (2008): Plant and small mammal richness correlate positively in a biodiversity hotspot – Biodiversity and Conservation **17**: 911–923.

Kemper, J., Cowling, R. M., Richardson, D. M. (1999): Fragmentation of South African Renosterveld shrublands: effects on plant community structure and conservation implications. – Biological Conservation **90**: 103–111.

Kemper, J., Cowling, R., Richardson, D., Forsyth, G., McKelly, D. (2000): Landscape fragmentation in South Coast Renosterveld, South Africa, in relation to rainfall and topography. – Austral Ecology **25**: 179–18

Kerley, G. (1992): Ecological correlates of small mammal community structure in the semi-arid Karoo, South Africa – Journal of Zoology **227**: 17–27.

Kieck, M.B. (2008): Comparative impacts of fragmentation on birds in two bioregions in a biodiversity hotspot, the Cape Floristic Region. – MSc Thesis. Stellenbosch: Stellenbosch University.

Kingdon, J. (1974): East african mammals. – London: Academic Press.

Kongor R.Y. (2009): Plant response to habitat fragmentation: clues from species and functional diversity in three Cape lowland vegetation types of South Africa. – PhD thesis. Stellenbosch: Stellenbosch University.

Kozakiewicz, M., Gortat, T., Kozakiewicz, A., Barkowska, M. (1999): Effects of habitat fragmentation on four rodent species in a Polish farm landscape. – Landscape Ecology **14**: 391–400.

Krug, C.B. (2002): Adaptations of the four-striped field mouse (*Rhabdomys pumilio* Sparman 1784) to the Namib Desert. – PhD thesis. Bonn: Rheinische Friedrich-Wilhelms Universität Bonn.

Krug, C.B., Krug, R.M., (2007): Restoration of old fields in Renosterveld: a case study in a Mediterranean shrubland of South Africa. – In: Cramer V.A., Hobbs R.J. (eds.): Old fields: dynamics and restoration of abandoned farmland: 265–285. – Washington, D.C.: Island Press.

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.

Lawson, D.M., Lamar, C.K., Schwartz, M.W. (2008): Quantifying plant population persistence in human–dominated landscapes. – Conservation Biology **22**: 922–928.

Lennartson, T. (2002): Extinction threshold and disrupted plant-pollinator interactions in fragmented plant populations. – Ecology **83**: 3060–3072.

Lindenmayer, D.B., J. Fischer (2006): Habitat fragmentation and landscape change: an ecological and conservation synthesis. – Washington, D.C.: Island Press.

Lloyd, P., Martin, T.E., Redmond, R.L., Langner, U., Hart, M.M. (2005): Linking demographic effects of habitat fragmentation across landscapes to continental source-sink dynamics. – Ecological Applications **15**: 1504–1514.

Luruli, N.M. (2007): Distribution and impact of the Argentine ant, *Linepithema humile* (Mayr), in South Africa. — MSc (Agric) thesis. Stellenbosch: Stellenbosch University.

MacDonald, D., Tew, T., Todd, I., Garner, J., Johnson, P. (2000): Arable habitat use by wood mice (*Apodemus sylvaticus*) 3. A farm-scale experiment on the effects of crop rotation – Journal of Zoology, London **250**: 313–320.

Magidi, J.T. (2010): Spatio-temporal dynamics in land use and habitat fragmentation in the Sandveld, South Africa. – MSc thesis: Bellville: University of the Western Cape.

Makady, E.M. (2009): Impact of herbivory by large game on plant palatability and plant diversity in West Coast Renosterveld. – MSc thesis. Stellenbosch: Stellenbosch University.

Major, R.E., Christie, F.J., Gowing, G., Cassis, G., Reid, C.A.M. (2003): The effect of habitat configuration on arboreal insects in fragmented woodlands of south-eastern Australia. – Biological Conservation **113**: 35–48.

Matthies, D., Bräuer, I., Maibom, W., Tscharntke, T. (2004): Population size and the risk of local extinction: empirical evidence from rare plants. – Oikos **105**: 481–488.

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

Memiaghe, H.R. (2008): Old field restoration: vegetation response to soil changes and restoration efforts in Western Cape lowlands. – MSc thesis. Stelenbosch: Stellenbosch University.

Mennechez, G., Clergeau, P. (2006): Effect of urbanisation on habitat generalists: starlings not so flexible? – Acta Oecologica **30:** 182–191.

Menzel, M. Ford, W. Laerm, J., Krishon, D. (1999): Forest to wildlife opening: habitat gradient analysis among small mammals in the southern Appalachians. – Forestry and Ecological Management **114**: 227–232.

Meyer, J., Kohnen, A., Harf, R., Froeschke, G., Brandl, R. (2006): Molecular markers for some small mammals of southern Africa. – Folia Zoologica **55**: 444–447.

Michel, N. Burel, F., Butet, A. (2006): How does landscape use influence small mammal diversity, abundance and biomass in hedgerow networks of farming landscapes? – Acta Oecologica **30**: 11–20.

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.

Midgley, J., Anderson, B., Bok, A., Fleming, T. (2002): Scatter-hoarding of Cape Proteaceae nuts by rodents. – Evolutionary Ecology Research **4**: 623–626.

Midgley, J.J., Anderson, B. (2005): Scatter hoarding in Mediterranean shrublands of the SW Cape, South Africa. – In: Forget, P.M, Lambert, J.E., Hulme, P.E., Vander Wall, S.B. (eds.): Seed fate: 197–204. Oxfordshire: CAB International.

Milton, S.J., Davies, G., Musil, C.F. (2004): Grasses as invasive alien plants in South Africa. – South African Journal of Science **100**: 69–75.

Morgan, J.W. (1999): Effects of population size on seed production and germinability in an endangered, fragmented grassland plant. – Conservation Biology **13**: 266–273.

Mortelliti, A., Boitani, L. (2009): Distribution and coexistence of shrews in patchy landscapes: a field test of multiple hypotheses. – Acta Oecologica **35**: 797–804.

Moseley, C. (2007): The impacts of grazing by large game species on small mammal community structure in west coast renosterveld. – Honours thesis. Cape Town: University of Cape Town.

Mucina, L., Rutherford, C. (eds.) (2006): The vegetation of South Africa, Lesotho and Swaziland. – Strelitzia **19**. Pretoria: South African National Biodiversity Institute.

Mugabe, J.C. (2008). Small mammal communities in the transformed landscapes of the Western Cape lowlands and their role in alien invasion into fynbos remnants. – MSc Thesis. Stellenbosch: Stellenbosch University.

Newton, I. (2008): Recent transformations in west-coast Renosterveld: patterns, processes and ecological significance. – PhD thesis. Bellville: University of the Western Cape.

Norris, K. (2008): Agriculture and biodiversity conservation: opportunity knocks. – Conservation Letters **1**: 2–11.

Pauw, A. (2004): Variation in pollination across a fragmented landscape at the Cape of Africa. – PhD thesis. Cape Town: University of Cape Town.

Pauw, A. (2007): Collapse of a pollination web in small conservation areas. – Ecology **88:** 1759–1769.

Picker, M.D., Samways, M.J. (1996): Faunal diversity and endemicity of the Cape Peninsula, South Africa - a first assessment. – Biodiversity and Conservation **5**: 591–606.

Pressey, R.L., Cowling, R.M., Rouget, M. (2003): Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. – Biological Conservation **112**: 99–127.

Primack, R.B. (2008): A primer of conservation biology. Ed. 4. – Sunderland: Sinauer Associates.

Procheş, Ş., Wilson, J.R.U., Veldtman, R., Kalwij, J.M., Richardson, D.M., Chown, S.L. (2005): Landscape corridors: possible dangers? – Science **310**: 781–783.

Pryke, J.S., Samways, M.J. (2009): Recovery of invertebrate diversity in a rehabilitated city landscape mosaic in the heart of a biodiversity hotspot. – Landscape and Urban Planning **93**: 54–62.

Quinn, J.F., Harrison, S.P. (1988): Effects of habitat fragmentation and isolation on species richness: evidence from biogeographic patterns. – Oecologia **75**: 132–140.

Radloff, F.G.T. (2008): The ecology of large herbivores native to the coastal lowlands of the Fynbos Biome in the Western Cape, South Africa. – PhD thesis. Stellenbosch: Stellenbosch University.

Rambau, R.V., Robinson, T.J., Stanyon, R. (2003): Molecular genetics of *Rhabdomys pumilio* subspecies boundaries: mtDNA phylogeography and karyotypic analysis by fluorescence in situ hybridization. – Molecular Phylogenetics and Evolution **28**: 564–575.

Randrianasolo, H. (2003): Birds in west coast Renosterveld fragments: implications for a threatened habitat. – MSc thesis. Cape Town: University of Cape Town.

Rebelo, A.G., Boucher, C., Helme, N., Mucina, L., Rutherford, M.C., Smit, W.J. Powrie, L.W., Ellis, F., Lambrechts, J.J., Scott, L. , Radloff, F.G.T., Johnson, S.D., Richardson, D.M., Ward, R.A., Procheş, Ş.M., Oliver, E.G.H., Manning, J.C., Jürgens, N., McDonald, D.J., Janssen, J.A.M., Walton, B.A., Le Roux, A., Skowno, A.L., Todd, S.W., Hoare, D.B. (2006): Fynbos Biome. – In: Mucina, L., Rutherford, M.C. (eds.): The Vegetation of South Africa, Lesotho and Swaziland: 52–219. Pretoria: South African National Biodiversity Institute.

Reisch C., Kaiser A.J., Horn A., Poschlod P. (2009): Genetic variation of *Mimetes hirtus* and *Mimetes fimbriifolius* (Proteaceae)–a comparative analysis of two closely related fynbos species. – Plant Biology **9**: 537–544.

Ries, L., Fletcher, R.J.J., Battin, J., Sisk, T.D. (2004): Ecological responses to habitat edges: mechanisms, models, and variability explained. – Annual Review of Ecology, Evolution and Systematics **35**: 491–522.

Rouget, M., Richardson, D.M., Cowling, R.M., Lloyd, J.W., Lombard, A.T. (2003a): Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. – Biological Conservation **112**: 63–85.

Rouget, M., Richardson, D.M., Cowling, R.M (2003b): The current configuration of protected areas in the Cape Floristic Region, South Africa – reservation bias and representation of biodiversity patterns and processes. – Biological Conservation **112:** 129–145.

Rouget, M., Cowling, R.M., Lombard, A.T., Knight, A.T., Kerley, G.I.H. (2005): Designing large-scale conservation corridors for pattern and process. – Conservation Biology **20**: 549–561.

Samways, M.J. (2005): Insect diversity conservation. – Cambridge: Cambridge University Press.

Samways, M.J. (2007): Insect conservation: a synthetic management approach. – Annual Review of Entomology **52**: 465–487.

Santos, T., Tellería, J.L., Corbonell, R. (2002): Bird conservation in fragmented Mediterranean forests of Spain: effects of geographical location, habitat and landscape degradation. – Biological Conservation **105**: 113–15.

Scherr, S.J., McNeely, J. A. (2008): Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. – Philosophical Transactions of the Royal Society B **363**: 477–494.

Schradin, C. (2005): When to live alone and when to live in groups: ecological determinants of sociality in the African striped mouse (*Rhabdomys pumilio*, Sparrman, 1784). – Belgian Journal of Zoology **135**(supplement): 77–82.

Schradin, C., Pillay, N. (2006): Female striped mice (*Rhabdomys pumilio*) change their home ranges in response to seasonal variation in food availability. – Behavioral Ecology **17**: 452–458.

Schweiger, E., Diffendorfer, J., Holt, R., Pierotti, R., Gaines, M. (2000): The interaction of habitat fragmentation, plant, and small mammal succession in an old field. – Ecological Monographs **70**: 383–400.

Shaffer, M.L. (1981): Minimum population sizes for species conservation. – BioScience **31**: 131–134.

Sharma, G.P., Muhl, S.A, Esler, K.J., Milton, S.J. (2010): Competitive interactions between the alien invasive annual grass *Avena fatua* and indigenous herbaceous plants in South African Renosterveld: the role of nitrogen enrichment. – Biological Invasions. DOI: 10.1007/s10530-010-9730-y.

Simberloff, D., Abele, L.G. (1982): Refuge design and island biogeographic theory: effects of fragmentation. – American Naturalist **120**: 41–50.

Stacy, J.E., Jorde, P.E., Steen, H., Ims, R.A., Purvis, A., Jakobsen, K.S. (1997): Lack of concordance between mtDNA gene flow and population density fluctuations in the bank vole. – Molecular Ecology **6**: 751–759.

Stokes, V.L., Pech, R.P., Banks, P.B., Arthur, A.D. (2005): Foraging behaviour and habitat use by *Antechinus flavipes* and *Sminthopsis murina* (Marsupialia: Dasyuridae) in response to predation risk in eucalypt woodland – Biological Conservation **117**: 331–342.

Sullivan, T.P., Sullivan, D.S. (2006): Plant and small mammal diversity in orchard versus non-crop habitats. – Agriculture, Ecosystems & Environment **116**: 235–243.

Tattersall, F., MacDonald, D., Hart, B., Manley, W., Feber, R. (2001): Habitat use by wood mice (*Apodemus sylvaticus*) in a changeable arable landscape. – Journal of Zoology, London **255**: 487–494.

Tew, T., Todd, I., MacDonald, D. (2000): Arable habitat use by wood mice (*Apodemus sylvaticus*) 2. – Microhabitat. – Journal of Zoology, London **250**: 305–311.

Todd, I., Tew, T., MacDonald, D. (2000): Arable habitat use by wood mice (*Apodemus sylvaticus*) 1. Macrohabitat. – Journal of Zoology, London 250: 299–303.

Trzcinski, M.K., Fahrig, L., Merriam, G. (1999): Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. – Ecological Applications **9**: 586–593.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C. (2005): Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. – Ecology Letters **8**: 857–874.

Urban, D., Keitt, T., (2001): Landscape connectivity: a graph-theoretic perspective. – Ecology **82**: 1205–1218.

Vamosi, J.C., Knight, T.M., Steets, J.A., Mazer, S.J., Burd, M., Ashman, T.L. (2006): Pollination decays in biodiversity hotspots. – Proceedings of the National Academy of Sciences **103**: 956–961.

Ward, M., S.D., Johnson (2005): Pollen limitation and demographic structure in small fragmented populations of *Brunsvigia radulosa* (Amaryllidaceae). – Oikos **108**: 253–262.

Watson, J.E.M., Whittaker, R.J., Freudenberger, D. (2005): Bird community responses to habitat fragmentation: how consistent are they across landscapes? – Journal of Biogeography **32**: 1353–1370.

Wester, P., Stanway, R., Pauw, A. (2009): Mice pollinate the Pagoda Lily, *Whiteheadia bifolia* (Hyacinthaceae) — first field observations with photographic documentation of rodent pollination in South Africa. – South African Journal of Botany **75**: 713–719.

Wirminghaus, J., Perrin, M. (1993): Seasonal changes in density, demography and body composition of small mammals in a southern temperate forest. – Journal of Zoology, London **229**: 303–318.

Witt, A.B.R., Samways, M.J. (2004): Influence of agricultural land transformation and pest management practices on the arthropod diversity of a biodiversity hotspot, the Cape Floristic Region, South Africa. – African Entomology **12**: 89–95.

Young, A., Boyle, T., Brown, T. (1996): The population genetic consequences of habitat fragmentation for plants. – Trends in Ecology and Evolution **11**: 413–418.

Part V

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Abbreviations

€	Euro
AALS	Affirmative Action Loan Scheme
AAN	Abattoir Association of Namibia
AAS	Affirmative Action Scheme
ACD	above cover density
AEZ	agro-ecological zones
aff.	affinis (Latin: related)
agg.	aggregate
AIC	Akaike information criterion
AM-fungi	arbuscular mycorrhizae fungi
ARC	Agricultural Research Council
AVHRR	Advanced Very High Resolution Radiometer
B	boron
BDM	Biodiversitäts-Monitoring Schweiz (Swiss Biodiversity Monitoring)
BG	bare ground
BMBF	Federal Ministry of Education and Research (Germany)
BSC	biological soil crusts
BSCI	biological soil crust index
C	carbon
C/N ratio	carbon-nitrogen ratio
Ca	calcium
CA	conservation agriculture
CAN	canopy
CASI	Compact Airborne Spectrographic Imager
CBD	Convention on Biological Diversity
CBNRM	community-based natural resource management
CCA	Canonical Correspondence Analysis
CEC	cation exchange capacity
cf.	confer (Latin: compare)
CI	crust index
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CRCIA	Continuum Removal Crust Identification Algorithm
CSF	critical success factors
Cu	copper
CV	coefficient of variation
DAP	draught animal power
DBH	stem diameter at breast height
DCSim	Devil's Claw Simulation tool
DED	Deutscher Entwicklungsdienst (German Development Service)
DEG	degraded
DEM	digital elevation model
DGGE	Denaturing Gradient Gel Electrophoresis
DNA	deoxyribonucleic acid
DSS	Decision Support System
E	Shannon evenness
EC	electrical conductivity
ECFSP	Emerging Commercial Farmer Support Programme
EESRaM	Ecological-Economic Savannah Rangeland Management tool
EF&S	ecosystem functions and services
ELTOSA	Environmental Long-Term Observation network of Southern Africa
EM	effective microorganisms
EMU	Ecosystem Management Understanding
ESSP	Earth System Science Partnership
ETM	Enhanced Thematic Mapper
FCC	Fertility Capability Classification
Fe	ferrum, iron
FT	functional traits
GCM	general circulation model
GEO BON	Group on Earth Observations Biodiversity Observation Network
GLM	generalised linear model
GTZ	Gesellschaft für Technische Zusammenarbeit
ha	hectare
IAD	Institutional Analysis and Development
IBM	individual-based model
ICEMA	integrated community-based ecosystem management
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
K	potassium
KBioSim	Kalahari Biodiversity Simulator
km	kilometre

κ	Kappa Index
LAI	Leaf Area Index
LCCS	Land Cover Classification System
LDC	Livestock Development Centre
LFA	Landscape Function Analysis
LLM	local level monitoring
LST	Land Surface Temperature
LSU	large stock unit; also: livestock unit
m	metre
MAP	mean annual precipitation
MAPOM	multi-annual programming and optimisation model
MAWF	Ministry of Agriculture, Water and Forestry (Namibia)
MET	Ministry of Environment and Tourism (Namibia)
Mg	magnesium
mm	millimetre
MODIS	Moderate Resolution Imaging Spectroradiometer
mRNA	messenger RNA
N	nitrogen
Na	natrium, sodium
NACOBTA	Namibia Community Based Tourism Assistance Trust
NARIS	Namibian Agricultural Resources Information System
NBRI	National Bontanical Research Institute of Namibia
NDT	Namibian Development Trust
NDVI	Normalised Difference Vegetation Index
NGO	Non-governmental Organisation
NMS	Nonmetrical Multidimensional Scaling
NNF	Namibia Nature Foundation
NPP	net primary production
NRF	South African National Research Foundation
OBS	obstacle
P	phosphate
PCA	Principal Component Analysis
PCoA	Principal Component Analysis
PCR	Polymerase Chain Reaction
PET	potential evapotranspiration
PFT	plant functional types
pH	potentiometric hydrogen ion concentration (measure of acidity)
PV	participatory video
R	taxonomic richness
RCM	regional climate model
REF	reference
REML	residual maximum likelihood
REMO	regional climate model
RNA	ribonucleic acid
RT-PCR	reverse-transcription-polymerase chain reaction
SAD	species abundance distribution
SADC	Southern African Development Community
SADCC	Southern African Development Coordination Conference
SAR	species-area relationship
SAST	South African Standard Time
SLA	specific leaf area
SOC	soil organic carbon
sp.	species
spp.	species (plural)
SR	summer rainfall
SRTM	Shuttle Radar Topographic Mission
SSB	soil seed bank
SSR	species-sampling relationship
SSU	small stock unit
subsp.	subspecies
SWC	south Western Cape
TCA	Traditional Conjoint-Analysis
TM	Landsat Thematic Mapper
T-RFLP	Terminal Restriction Fragment Length Polymorphism
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on the Environment and Development
var.	variety
VHR	very high resolution
WR	winter rainfall
WRB	World Reference Base for Soil Resources
WWF	World Wide Fund for Nature
Ys	photosynthetic quantum yields at a steady state
*	corresponding author

List of scientific names

The list includes all scientific names, as well as the authors and families, of the lichens, vascular plants, and animals mentioned in the text of the three volumes. The names are arranged in alphabetical order (genus, epitethon). The abbreviation at the beginning of each entry indicates the main groups of organisms treated here: AVES = birds, DIPL = Diplopoda (millipeds), GAST = Gastropoda, INSE = insects, LICH = lichens, MAM = mammals, REPT = reptiles, VASC = vascular plants.

VASC	*Abildgaardia triflora* (L.) Abeyw. — Cyperaceae
VASC	*Abutilon angulatum* (Guill. & Perr.) Mast. — Malvaceae
VASC	*Abutilon austro-africanum* Hochr. — Malvaceae
VASC	*Abutilon hirtum* (Lam.) Sweet — Malvaceae
VASC	*Acacia arenaria* Schinz — Fabaceae
VASC	*Acacia ataxacantha* DC. — Fabaceae
VASC	*Acacia cyclops* A.Cunn. ex G.Don — Fabaceae
VASC	*Acacia erioloba* E.Mey. — Fabaceae
VASC	*Acacia erubescens* Welw. ex Oliv. — Fabaceae
VASC	*Acacia fleckii* Schinz — Fabaceae
VASC	*Acacia haematoxylon* Willd. — Fabaceae
VASC	*Acacia hebeclada* DC. subsp. *hebeclada* — Fabaceae
VASC	*Acacia hereroensis* Engl. — Fabaceae
VASC	*Acacia karroo* Hayne — Fabaceae
VASC	*Acacia kirkii* Oliv. — Fabaceae
VASC	*Acacia luederitzii* Engl. — Fabaceae
VASC	*Acacia luederitzii* Engl. var. *luederitzii* — Fabaceae
VASC	*Acacia melanoxylon* R.Br. — Fabaceae
VASC	*Acacia mellifera* (Vahl) Benth. — Fabaceae
VASC	*Acacia mellifera* subsp. *detinens* (Burch.) Brenan — Fabaceae
VASC	*Acacia nebrownii* Burtt Davy — Fabaceae
VASC	*Acacia nilotica* (L.) Willd. ex Delile — Fabaceae
VASC	*Acacia reficiens* Wawra & Peyr. — Fabaceae
VASC	*Acacia reficiens* Wawra & Peyr. subsp. *reficiens* — Fabaceae
VASC	*Acacia saligna* (Labill.) H.L.Wendl — Fabaceae
VASC	*Acacia senegal* (L.) Willd. — Fabaceae
VASC	*Acacia tortilis* (Forssk.) Hayne — Fabaceae
VASC	*Acacia tortilis* subsp. *heteracantha* (Burch.) Brenan — Fabaceae
VASC	*Acalypha indica* L. — Euphorbiaceae
VASC	*Acalypha segetalis* Müll.Arg. — Euphorbiaceae
VASC	*Acalypha villicaulis* Hochst. — Euphorbiaceae
INSE	*Acanthaspis oscura* (Stål, 1855) — Reduviidae
INSE	*Acantholipes trimeni* Felder & Rogenhofer, 1874 — Noctuidae
VASC	*Acanthopsis carduifolia* (L.f.) Schinz — Acanthaceae
VASC	*Acanthopsis disperma* Nees — Acanthaceae
VASC	*Acanthopsis hoffmannseggiana* (Nees) C.B.Clarke — Acanthaceae
VASC	*Acanthosicyos naudinianus* (Sond.) C.Jeffrey — Cucurbitaceae
VASC	*Acanthospermum hispidum* DC. — Asteraceae
LICH	*Acarospora gypsi-deserti* nom. nud. — Acarosporaceae
LICH	*Acarospora luederitzensis* H. Magn. — Acarosporaceae
LICH	*Acarospora ochrophaea* H. Magn. — Acarosporaceae
LICH	*Acarospora strigata* (Nyl.) Jatta — Acarosporaceae
AVES	*Achaetops pycnopygius* (Slater, 1852) — Sylviidae
INSE	*Achyra coelatalis* (Walker, 1859) — Crambidae
INSE	*Achyra nudalis* (Hübner, 1796) — Crambidae
VASC	*Achyranthes aspera* L. — Amaranthaceae
VASC	*Achyranthes aspera* L. var. *aspera* — Amaranthaceae
VASC	*Achyranthes aspera* var. *sicula* L. — Amaranthaceae
INSE	*Aciagrion* (*Aciagrion*) *steeleae* Kimmins, 1955 — Coenagrionidae
INSE	*Aciagrion* (*Mombagrion*) *heterostictum* Fraser, 1955 — Coenagrionidae
INSE	*Acisoma panorpoides ascalaphoides* Rambur, 1842 — Libellulidae
INSE	*Acrea neobule neobule* Doubleday, 1847 — Nymphalidae
INSE	*Acrea stenobea* (Walllengren, 1860) — Nymphalidae
AVES	*Acrocephalus baeticatus* (Vieilott, 1817) — Acrocephalidae
VASC	*Acrolophia lamellata* (Lindl.) Schltr. & Bolus — Orchidaceae
VASC	*Acrosanthes angustifolia* Eckl. & Zeyh. — Aizoaceae
VASC	*Acrosanthes teretifolia* Eckl. & Zeyh. — Aizoaceae
INSE	*Acrosternum apicale* Linnavuori, 1975 — Pentatomidae
VASC	*Acrotome angustifolia* G.Taylor — Lamiaceae
VASC	*Acrotome fleckii* (Gürke) Launert — Lamiaceae
VASC	*Acrotome inflata* Benth. — Lamiaceae
INSE	*Acutitornus munda* Janse, 1951 — Gelechiidae
VASC	*Adenandra villosa* (P.J.Bergius) Licht. ex Roem. & Schult. — Rutaceae
VASC	*Adenia repanda* (Burch.) Engl. — Passifloraceae
VASC	*Adenogramma glomerata* (L.f.) Druce — Molluginaceae
VASC	*Adenogramma mollugo* Rchb.f. — Molluginaceae
VASC	*Adenolobus garipensis* (E. Meyer) Torre & Hillcoat — Fabaceae
VASC	*Adenolobus pechuelii* (Kuntze) Torre & Hillc. — Fabaceae
INSE	*Aderrhis pulla* Bergroth, 1906 — Pyrrhocoridae
VASC	*Adromischus alstonii* (Schönland & Baker f.) C.A.Sm. — Crassulaceae
VASC	*Adromischus filicaulis* (Eckl. & Zeyh.) C.A.Sm. — Crassulaceae
VASC	*Adromischus filicaulis* (Eckl. & Zeyh.) C.A.Sm. subsp. *filicaulis* — Crassulaceae
VASC	*Adromischus marianiae* (Marloth) A.Berger — Crassulaceae
VASC	*Adromischus marianiae* var. *immaculatus* Uitewaal — Crassulaceae
INSE	*Aeliomorpha pumila* Stål, 1853 — Pentatomidae
INSE	*Aeliomorpha senegalensis* Signoret, 1851 — Pentatomidae
VASC	*Aerva leucura* Moq. — Amaranthaceae
VASC	*Aeschynomene indica* L. — Fabaceae
INSE	*Aeshna minuscula* McLachlan, 1896 — Aeshnidae
INSE	*Aeshna subpupillata* Mclachlan, 1896 — Aeshnidae
INSE	*Aethalopteryx dictyotephra* (Clench, 1959) — Cossidae
INSE	*Aethiothemis solitaria* Martin, 1908 — Libellulidae
INSE	*Aethriamanta rezia* Kirby, 1889 — Libellulidae
INSE	*Aethus lautipennis* (Stål, 1858) — Cydnidae
INSE	*Aethus perosus* Stål, 1854 — Cydnidae
INSE	*Aethus sculptus* Gerstaecker, 1873 — Cydnidae
INSE	*Afranthidium* cf. *odonturum* (Cockerell, 1932) — Megachilidae
INSE	*Afranthidium* Michener, 1948 — Megachilidae
DIPL	*Afraustraloxenodes coineaui* Nguyen Duy-Jacquemin 2003 — Polyxenidae
INSE	*Africallagma glaucum* (Burmeister, 1839) — Coenagrionidae
INSE	*Africallagma sapphirinum* (Pinhey, 1950) — Coenagrionidae
INSE	*Africallagma subtile* (Ris, 1921) — Coenagrionidae
INSE	*Afrius yolofa* (Guérin-Méneville, 1831) — Pentatomidae
VASC	*Afrolimon purpuratum* (L.) Lincz. — Plumbaginaceae
VASC	*Afrolimon teretifolium* (L.) Lincz. — Plumbaginaceae
INSE	*Afrotingis mboloko* Linnavuori, 1977 — Tingidae
AVES	*Afrotis afra* (Linnaeus, 1758) — Otididae
AVES	*Afrotis afraoides* (A.Smith, 1831) — Otididae
REPT	*Agama hispida* (Kaup, 1827) — Agamidae
VASC	*Agathosma ciliaris* (L.) Druce — Rutaceae
VASC	*Agathosma hookeri* Sond. — Rutaceae
VASC	*Agathosma imbricata* (L.) Willd. — Rutaceae
VASC	*Agathosma serpyllacea* Licht. ex Roem. & Schult. — Rutaceae
INSE	*Agdistis eberti* Arenberger, 2009 — Pterophoridae
INSE	*Agdistis meyi* Arenberger, 2008 — Pterophoridae
INSE	*Agonoscelis puberula* Stål, 1853 — Pentatomidae
INSE	*Agraphopus antennatus* Distant, 1918 — Rhopalidae
INSE	*Agraphopus bergrothi* Schouteden, 1912 — Rhopalidae
INSE	*Agriocnemis angolensis* Longfield, 1947 — Coenagrionidae
INSE	*Agriocnemis exilis* Selys, 1872 — Coenagrionidae
INSE	*Agriocnemis falcifera* Pinhey, 1959 — Coenagrionidae

INSE	*Agriocnemis gratiosa* Gerstäcker, 1891 — Coenagrionidae
INSE	*Agriocnemis ruberrima* Balinsky, 1961 — Coenagrionidae
INSE	*Agriocnemis victoria* Fraser, 1928 — Coenagrionidae
INSE	*Agrotis ipsilon* (Hufnagel, 1766) — Noctuidae
VASC	*Aira cupaniana* Guss. — Orchidaceae
VASC	*Aizoanthemum dinteri* (Schinz) Friedrich — Aizoaceae
VASC	*Aizoanthemum galenioides* (Fenzl ex Sonder) Friedrich — Aizoaceae
VASC	*Aizoon asbestinum* Schltr. — Aizoaceae
VASC	*Aizoon canariense* L. — Aizoaceae
VASC	*Aizoon giessii* Friedrich — Aizoaceae
VASC	*Aizoon sarmentosum* L.f. — Aizoaceae
VASC	*Aizoon schellenbergii* Adamson — Aizoaceae
VASC	*Aizoon virgatum* Welw. ex Oliv. — Aizoaceae
INSE	*Alastor* Lepeletier, 1841 — Eumenidae
INSE	*Alastor ricae* Giordani Soika, 1934 — Eumenidae
VASC	*Albizia anthelmintica* (A.Rich.) Brongn. — Fabaceae
VASC	*Albizia antunesiana* Harms — Fabaceae
VASC	*Albuca acuminata* Baker — Hyacinthaceae
VASC	*Albuca cooperi* Baker — Hyacinthaceae
VASC	*Albuca echinosperma* U.Müll.-Doblies — Hyacinthaceae
VASC	*Albuca juncifolia* Baker — Hyacinthaceae
VASC	*Albuca longipes* Baker — Hyacinthaceae
VASC	*Albuca maxima* Burm.f. — Hyacinthaceae
VASC	*Albuca navicula* U.Müll.-Doblies — Hyacinthaceae
VASC	*Albuca spiralis* L.f. — Hyacinthaceae
VASC	*Albuca suaveolens* (Jacq.) J.C.Manning & Goldblatt — Hyacinthaceae
VASC	*Albuca viscosa* L.f. — Hyacinthaceae
VASC	*Alectra pseudobarleriae* (Dinter) Dinter — Scrophulariaceae
INSE	*Alenia namaqua* (Vari, 1974) — Hesperidae
INSE	*Allocnemis leucosticta* Selys, 1863 — Platycnemididae
INSE	*Allocoelia* Mocsáry, 1889 — Chrysididae
INSE	*Allocoelia mocsaryi* (Brauns, 1903) — Chrysididae
INSE	*Allodontermes* Silvestri, 1914 — Termitidae
VASC	*Aloe dichotoma* Masson — Asphodelaceae
VASC	*Aloe dichotoma* var. *ramosissima* (Pillans) Glen & D.S.Hardy — Asphodelaceae
VASC	*Aloe krapohliana* Marloth — Asphodelaceae
VASC	*Aloe melanacantha* A.Berger — Asphodelaceae
VASC	*Aloe pearsonii* Schönland — Asphodelaceae
VASC	*Aloe pillansii* L.Guthrie — Asphodelaceae
VASC	*Aloe variegata* L. — Asphodelaceae
VASC	*Aloe zebrina* Baker — Asphodelaceae
INSE	*Aloiedes barklyi* (Trimen, 1874) — Lycaenidae
INSE	*Aloiedes damarensis damarensis* (Trimen, 1891) — Lycaenidae
INSE	*Aloiedes damarensis mashona* (Tite & Dickson, 1973) — Lycaenidae
AVES	*Alopochen aegyptiacus* (Linnaeus, 1766) — Anatidae
VASC	*Alternanthera pungens* Kunth — Amaranthaceae
LICH	*Amandinea extenuata* (Müll. Arg.) Marbach — Physciaceae
LICH	*Amandinea insperata* (Nyl.) H. Mayrhofer & Ropin — Physciaceae
LICH	*Amandinea punctata* (Hoffm.) Coppins & Scheid. — Physciaceae
VASC	*Amaranthus dinteri* Schinz — Amaranthaceae
VASC	*Amaranthus dinteri* Schinz subsp. *dinteri* — Amaranthaceae
VASC	*Amaranthus praetermissus* Brenan — Amaranthaceae
VASC	*Amaranthus schinzianus* Thell. — Amaranthaceae
VASC	*Amaranthus thunbergii* Moq. — Amaranthaceae
VASC	*Amellus microglossus* DC. — Asteraceae
VASC	*Amellus nanus* DC. — Asteraceae
INSE	*Amitermes* Silvestri, 1901 — Termitidae
VASC	*Ammannia baccifera* L. — Lythraceae
VASC	*Ammocharis coranica* (Ker Gawl.) Herb. — Amaryllidaceae
AVES	*Ammomanes grayi* (Wahlberg, 1855) — Alaudidae
VASC	*Amphiasma divaricatum* (Engl.) Bremek. — Rubiaceae
VASC	*Amphiasma merenskyanum* Bremek. — Rubiaceae
VASC	*Amphibolia saginata* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Amphibolia succulenta* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Amphiglossa tomentosa* (Thunb.) Harv. — Asteraceae
VASC	*Amphithalea ericifolia* (L.) Eckl. & Zeyh. — Fabaceae
VASC	*Amsinckia calycina* (Moris) Chater — Boraginaceae
VASC	*Amsinckia retrorsa* Suksd. — Boraginaceae
INSE	*Amyna punctum* (Fabricius, 1794) — Noctuidae
VASC	*Anacampseros baeseckei* Dinter — Portulacaceae
VASC	*Anacampseros filamentosa* subsp. *namaquensis* (H.Pearson & Stephens) G.D.Rowley — Portulacaceae
VASC	*Anacampseros lanceolata* (Haw.) Sweet subsp. *lanceolata* — Portulacaceae
VASC	*Anacampseros retusa* Poelln. — Portulacaceae
INSE	*Anax bangweuluensis* Kimmins, 1955 — Aeshnidae
INSE	*Anax ephippiger* (Burmeister, 1839) — Aeshnidae
INSE	*Anax imperator* Leach, 1815 — Aeshnidae
INSE	*Anax speratus* Hagen, 1867 — Aeshnidae
INSE	*Anax tristis* Hagen, 1867 — Aeshnidae
VASC	*Anaxeton laeve* (Harv.) Lundgren — Asteraceae
INSE	*Andocides vittaticeps* Stål, 1876 — Pentatomidae
VASC	*Androcymbium burchellii* Baker — Colchicaceae
VASC	*Androcymbium roseum* Engl. — Colchicaceae
VASC	*Androcymbium villosum* U.Müll.-Doblies & D.Müll.-Doblies — Colchicaceae
VASC	*Andropogon chinensis* (Nees) Merr. — Poaceae
VASC	*Andropogon schirensis* A.Rich. — Poaceae
INSE	*Angulitermes* Sjöstedt, 1924 — Termitidae
INSE	*Anharmostes papilio* Prout, 1912 — Geometridae
AVES	*Anhinga melanogaster rufa* (Daudin, 1802) — Anhingidae
VASC	*Anisodontea triloba* (Thunb.) Bates — Malvaceae
INSE	*Anisops debilis* Gerstaecker, 1873 — Notonectidae
INSE	*Anisops sardeus madagascariensis* Poisson, 1937 — Notonectidae
INSE	*Anisops varius* Fieber, 1851 — Notonectidae
INSE	*Anoplolepis steingroeveri (Forel, 1894)* — Formicidae
INSE	*Antestia maculata* (Dallas, 1851) — Pentatomidae
VASC	*Anthephora pubescens* Nees — Poaceae
VASC	*Anthephora schinzii* Hack. — Poaceae
INSE	*Anthophora* Latreille, 1803 — Apidae
AVES	*Anthoscopus minutus* (Shaw & Nodder, 1812) — Remizidae
VASC	*Anthospermum aethiopicum* L. — Rubiaceae
VASC	*Anthospermum bergianum* Cruse — Rubiaceae
VASC	*Anthospermum dregei* Sond. subsp. *dregei* — Rubiaceae
VASC	*Anthospermum galioides* Rchb.f. — Rubiaceae
LICH	*Anthracocarpon virescens* (Zahlbr.) Breuss — Verrucariaceae
INSE	*Anthrax anthrax* (Schrank, 1781) — Bombyliidae
INSE	*Anthrax* Scopoli, 1763 — Bombyliidae
VASC	*Anticharis inflata* Marloth & Engl. — Scrophulariaceae
VASC	*Anticharis senegalensis* (Walp.) Bhandari — Scrophulariaceae
MAM	*Antidorcas marsupialis* (Zimmermann, 1780) — Bovidae
VASC	*Antimima defecta* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Antimima dualis* (N.E.Br.) N.E.Br. — Aizoaceae
VASC	*Antimima excedens* (L.Bolus) Klak — Aizoaceae
VASC	*Antimima hantamensis* (Engl.) H.E.K. Hartmann & Stüber — Aizoaceae
VASC	*Antimima intervallaris* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Antimima komkansica* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Antimima leipoldtii* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Antimima pumila* (Fedde & Schuster) H.E.K.Hartmann — Aizoaceae
VASC	*Antimima solida* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Antimima watermeyeri* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Antizoma angustifolia* (Burch.) Miers ex Harv. — Menispermaceae
VASC	*Antizoma miersiana* Harv. — Menispermaceae
VASC	*Apatesia pillansii* N.E.Br. — Aizoaceae
INSE	*Apolysis capicola* Hesse, 1975 — Bombyliidae
VASC	*Aponogeton angustifolius* Aiton — Aponogetonaceae
VASC	*Aponogeton junceus* Lehm. — Aponogetonaceae
VASC	*Aptosimum albomarginatum* Marloth & Engler — Scrophulariaceae
VASC	*Aptosimum angustifolium* F.E.Weber & Schinz — Scrophulariaceae
VASC	*Aptosimum arenarium* Engl. — Scrophulariaceae
VASC	*Aptosimum decumbens* Schinz — Scrophulariaceae
VASC	*Aptosimum elongatum* Engl. — Scrophulariaceae
VASC	*Aptosimum glandulosum* Weber & Schinz — Scrophulariaceae
VASC	*Aptosimum indivisum* Burch. ex Benth. — Scrophulariaceae
VASC	*Aptosimum lineare* Marloth & Engl. — Scrophulariaceae
VASC	*Aptosimum lugardiae* (N.E.Br.) E.Phillips — Scrophulariaceae
VASC	*Aptosimum marlothii* (Engl.) Hiern — Scrophulariaceae

VASC	*Aptosimum spinescens* (Thunb.) F.E. Weber — Scrophulariaceae
VASC	*Aptosimum suberosum* F.E.Weber — Scrophulariaceae
VASC	*Aptosimum tragacanthoides* E.Mey. ex Benth. — Scrophulariaceae
AVES	*Aquila rapax* (Temminck, 1828) — Cathartidae
VASC	*Arctopus echinatus* L. — Apiaceae
VASC	*Arctopus monacanthus* Carmich. ex Sond. — Apiaceae
VASC	*Arctotheca calendula* (L.) Levyns — Asteraceae
VASC	*Arctotis acaulis* L. — Asteraceae
VASC	*Arctotis angustifolia* L. — Asteraceae
VASC	*Arctotis aspera* L. — Asteraceae
VASC	*Arctotis auriculata* Jacq. — Asteraceae
VASC	*Arctotis campanulata* DC. — Asteraceae
VASC	*Arctotis fastuosa* Jacq. — Asteraceae
VASC	*Arctotis incisa* Thunb. — Asteraceae
VASC	*Arctotis laevis* Thunb. — Asteraceae
VASC	*Arctotis merxmuelleri* Friedrich — Asteraceae
VASC	*Arctotis undulata* Jacq. — Asteraceae
AVES	*Ardeotis kori* (Burchell, 1822) — Otididae
VASC	*Arenifera pillansii* (L.Bolus) Herre — Aizoaceae
VASC	*Arenifera stylosa* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Argemone ochroleuca* Sweet subsp. *ochroleuca* — Papaveraceae
VASC	*Argyroderma crateriforme* (L.Bolus) N.E.Br. — Aizoaceae
VASC	*Argyroderma delaetii* C.A.Maass — Aizoaceae
VASC	*Argyroderma fissum* (Haw.) L.Bolus — Aizoaceae
VASC	*Argyroderma framesii* L.Bolus subsp. *framesii* — Aizoaceae
VASC	*Argyroderma framesii* subsp. *hallii* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Argyroderma patens* L.Bolus — Aizoaceae
VASC	*Argyroderma pearsonii* (N. E. Br.) Schwant. — Aizoaceae
VASC	*Argyroderma testiculare* (Aiton) N.E.Br. — Aizoaceae
VASC	*Argyrolobium velutinum* Eckl. & Zeyh. — Fabaceae
VASC	*Aridaria brevicarpa* L.Bolus — Aizoaceae
VASC	*Aridaria noctiflora* (L.) Schwantes — Aizoaceae
VASC	*Aridaria noctiflora* (L.) Schwantes subsp. *noctiflora* — Aizoaceae
VASC	*Aridaria noctiflora* subsp. *defoliata* (Haw.) Gerbaulet — Aizoaceae
VASC	*Aridaria serotina* L.Bolus — Aizoaceae
VASC	*Aristea africana* (L.) Hoffmanns — Iridaceae
VASC	*Aristea confusa* Goldblatt — Iridaceae
VASC	*Aristea juncifolia* Baker — Iridaceae
VASC	*Aristea spiralis* (L.f.) Ker Gawl. — Iridaceae
VASC	*Aristida adscensionis* L. — Poaceae
VASC	*Aristida congesta* Roem. & Schult. — Poaceae
VASC	*Aristida congesta* Roem. & Schult. subsp. *congesta* — Poaceae
VASC	*Aristida diffusa* Trin. — Poaceae
VASC	*Aristida effusa* Henrard — Poaceae
VASC	*Aristida engleri* Mez var. *engleri* — Poaceae
VASC	*Aristida hordeacea* Kunth — Poaceae
VASC	*Aristida junciformis* Trin. & Rupr. — Poaceae
VASC	*Aristida meridionalis* Henrard — Poaceae
VASC	*Aristida parvula* (Nees) De Winter — Poaceae
VASC	*Aristida pilgeri* Henrard — Poaceae
VASC	*Aristida rhiniochloa* Hochst. — Poaceae
VASC	*Aristida stipitata* Hack. — Poaceae
VASC	*Aristida stipitata* Hack. subsp. *stipitata* — Poaceae
VASC	*Aristida stipitata* subsp. *graciliflora* (Pilg.) Melderis — Poaceae
VASC	*Aristida stipoides* Lam. — Poaceae
LICH	*Arthonia* aff. *arthonioides* (Ach.) A. L. Sm. — Arthoniaceae
LICH	*Arthonia punctiformis* Ach. — Arthoniaceae
LICH	*Arthonia radiata* (Pers.) Ach. — Arthoniaceae
LICH	*Arthopyrenia subcerasi* (Vain.) Zahlbr. — Arthopyreniaceae
VASC	*Arthraerua leubnitziae* (Kuntze) Schinz — Amaranthaceae
VASC	*Asclepias crispa* P.J.Bergius — Asclepiadaceae
VASC	*Aspalathus abietina* Thunb. — Fabaceae
VASC	*Aspalathus aculeata* Thunb. — Fabaceae
VASC	*Aspalathus biflora* E.Mey. subsp. *biflora* — Fabaceae
VASC	*Aspalathus capensis* (Walp.) R.Dahlgren — Fabaceae
VASC	*Aspalathus ciliaris* L. — Fabaceae
VASC	*Aspalathus cuspidata* R.Dahlgren — Fabaceae
VASC	*Aspalathus ericifolia* L. — Fabaceae
VASC	*Aspalathus hispida* Thunb. subsp. *hispida* — Fabaceae
VASC	*Aspalathus horizontalis* (R.Dahlgren) R.Dahlgren — Fabaceae
VASC	*Aspalathus microphylla* DC. — Fabaceae
VASC	*Aspalathus parviflora* P.J.Bergius — Fabaceae
VASC	*Aspalathus quinquefolia* L. — Fabaceae
VASC	*Aspalathus retroflexa* L. — Fabaceae
VASC	*Aspalathus sericea* P.J.Bergius — Fabaceae
VASC	*Aspalathus spinosa* L. — Fabaceae
VASC	*Aspalathus spinosa* L. subsp. *spinosa* — Fabaceae
VASC	*Aspalathus tridentata* L. — Fabaceae
VASC	*Asparagus aethiopicus* L. — Asparagaceae
VASC	*Asparagus africanus* Lam. — Asparagaceae
VASC	*Asparagus aspergillus* Jessop — Asparagaceae
VASC	*Asparagus bayeri* (Oberm.) Fellingham & N.L.Mey. — Asparagaceae
VASC	*Asparagus bechuanicus* Baker — Asparagaceae
VASC	*Asparagus burchelli* (Knuth) Baker — Asparagaceae
VASC	*Asparagus capensis* L. — Asparagaceae
VASC	*Asparagus cooperi* Baker — Asparagaceae
VASC	*Asparagus denudatus* (Knuth) Baker — Asparagaceae
VASC	*Asparagus exuvialis* Burch. — Asparagaceae
VASC	*Asparagus fasciculatus* Thunb. — Asparagaceae
VASC	*Asparagus juniperoides* Engl. — Asparagaceae
VASC	*Asparagus kraussianus* (Kunth) J.F.Macbr. — Asparagaceae
VASC	*Asparagus lignosus* Burm.f. — Asparagaceae
VASC	*Asparagus multituberosus* R.A.Dyer — Asparagaceae
VASC	*Asparagus nelsii* Schinz — Asparagaceae
VASC	*Asparagus pearsonii* Kies — Asparagaceae
VASC	*Asparagus pendulus* (Oberm.) J.-P. Lebrun & Stork — Asparagaceae
VASC	*Asparagus recurvispinus* (Oberm.) Fellingham & N.L.Mey. — Asparagaceae
VASC	*Asparagus retrofractus* L. — Asparagaceae
VASC	*Asparagus rubicundus* P.J.Bergius — Asparagaceae
VASC	*Asparagus scandens* Thunb. — Asparagaceae
VASC	*Asparagus suaveolens* Burch. — Asparagaceae
VASC	*Asparagus undulatus* (L.f.) Thunb. — Asparagaceae
VASC	*Asparagus virgatus* Baker — Asparagaceae
VASC	*Aspazoma amplectens* (L.Bolus) N.E.Br. — Aizoaceae
REPT	*Aspidelaps lubricus* Laurenti, 1768 — Elapidae
REPT	*Aspidelaps scutatus* Smith, 1849 — Elapidae
INSE	*Aspilocoryphus fasciativentris* (Stål, 1858) — Lygaeidae
VASC	*Asplenium gemmiferum* Schrad. — Aspleniaceae
VASC	*Aster subulatus* Michx. — Asteraceae
VASC	*Astridia longifolia* (L.Bolus) L.Bolus — Aizoaceae
VASC	*Astridia speciosa* L.Bolus — Aizoaceae
VASC	*Astripomoea rotundata* (Pilg.) A.Meeuse — Convolvulaceae
VASC	*Athanasia crenata* (L.) L. — Asteraceae
VASC	*Athanasia rugulosa* E.Mey. ex DC. — Asteraceae
VASC	*Athanasia trifurcata* (L.) L. — Asteraceae
VASC	*Atriplex lindleyi* subsp. *inflata* (F.Muell.) Paul G. Wilson — Chenopodiaceae
VASC	*Atriplex semibaccata* R.Br — Chenopodiaceae
VASC	*Atriplex vestita* (Thunb.) Aellen — Chenopodiaceae
VASC	*Augea capensis* Thunb. — Zygophyllaceae
INSE	*Austroplacodema bicolorata* Sobczyk & Mey, 2007 — Psychidae
VASC	*Avonia albissima* (Mar.) G.D.Rowley — Portulacaceae
VASC	*Avonia papyracea* subsp. *namaensis* (Gerbaulet) G.D.Rowley — Portulacaceae
VASC	*Avonia quinaria* (E.Mey.ex Fenzl) G.D.Rowley subsp. *quinaria* — Portulacaceae
INSE	*Axiocerses amanga amanga* (Westwood, 1881) — Lycaenidae
INSE	*Axiocerses tjoane* (Wallengren, 1957) — Lycaenidae
INSE	*Azanus jesous jesous* (Guérin-Meneville, 1849) — Lycaenidae
INSE	*Azanus ubaldus ubaldus* (Stoll, 1782) — Lycaenidae
INSE	*Azuragrion nigridorsum* (Selys, 1876) — Coenagrionidae
VASC	*Babiana ambigua* (Roem. & Schult.) G.J.Lewis — Iridaceae
VASC	*Babiana angustifolia* Sweet — Iridaceae
VASC	*Babiana attenuata* G.J.Lewis — Iridaceae
VASC	*Babiana dregei* Baker — Iridaceae
VASC	*Babiana ringens* (L.) Ker Gawl. — Iridaceae
VASC	*Babiana secunda* (Thunb.) Ker Gawl. — Iridaceae
VASC	*Babiana sinuata* G.J.Lewis — Iridaceae
VASC	*Baeometra uniflora* (Jacq.) G.J.Lewis — Colchicaceae
INSE	*Bagrada hilaris* Burmeister, 1835 — Pentatomidae
VASC	*Baikiaea plurijuga* Harms — Fabaceae
VASC	*Baissea wulfhorstii* Schinz — Apocynaceae
VASC	*Ballota africana* (L.) Benth. — Lamiaceae

VASC	*Baphia massaiensis* subsp. *obovata* (Schinz) Brummitt var. *obovata* — Fabaceae
INSE	*Barberocoris myrmecoides* Slater & Sweet, 1970 — Oxycarenidae
VASC	*Barleria albi-pilosa* Hainz — Acanthaceae
VASC	*Barleria galpinii* C.B.Clarke — Acanthaceae
VASC	*Barleria kaloxytona* Lindau — Acanthaceae
VASC	*Barleria lanceolata* (Schinz) Oberm. — Acanthaceae
VASC	*Barleria lancifolia* T.Anderson — Acanthaceae
VASC	*Barleria mackenii* Hook.f. — Acanthaceae
VASC	*Barleria macrostegia* Nees — Acanthaceae
VASC	*Barleria rigida* Nees — Acanthaceae
VASC	*Basananthe pedata* (Baker f.) W.J.de Wilde — Passifloraceae
AVES	*Batis molitor* (Küster, 1850) — Platysteiridae
AVES	*Batis pririt* (Vieillot, 1818) — Platysteiridae
INSE	*Baucaliotermes hainesi* (Fuller, 1922) — Termitidae
VASC	*Bauhinia petersiana* Bolle — Fabaceae
VASC	*Bauhinia petersiana* subsp. *macrantha* (Oliv.) Brummitt & J.H.Ross — Fabaceae
VASC	*Becium filamentosum* (Forssk.) Chiov. — Lamiaceae
INSE	*Belenois aurota aurota* (Fabricius, 1793) — Pieridae
INSE	*Bembecinus* A. Costa, 1859 — Crabronidae
VASC	*Berkheya armata* (Vahl) Druce — Asteraceae
VASC	*Berkheya canescens* DC. — Asteraceae
VASC	*Berkheya fruticosa* Ehrh. — Asteraceae
VASC	*Berkheya onobromoides* (DC.) O.Hoffm. & Muschl. — Asteraceae
VASC	*Berkheya spinosissima* (Thunb.) Willd. — Asteraceae
VASC	*Berzelia abrotanoides* (L.) Brongn. — Bruniaceae
VASC	*Bidens bipinnata* L. — Asteraceae
VASC	*Bidens biternata* (Lour.) Merr. & Scherff — Asteraceae
VASC	*Bidens pilosa* L. — Asteraceae
VASC	*Bidens schimperi* Sch. Bip. ex Walp. — Asteraceae
REPT	*Bitis arietans* (Merrem, 1820) — Viperidae
REPT	*Bitis caudalis* Smith, 1839 — Viperidae
VASC	*Blepharis diversispina* (Nees) C.B.Clarke — Acanthaceae
VASC	*Blepharis furcata* (L.f.) Pers. — Acanthaceae
VASC	*Blepharis grossa* (Nees) T.Anderson — Acanthaceae
VASC	*Blepharis integrifolia* (L.f.) E.Mey. ex Schinz var. *integrifolia* — Acanthaceae
VASC	*Blepharis leendertziae* Oberm. — Acanthaceae
VASC	*Blepharis maderaspatensis* (L.) Roth — Acanthaceae
VASC	*Blepharis mitrata* C.B.Clarke — Acanthaceae
VASC	*Blepharis obmitrata* C.B.Clarke — Acanthaceae
VASC	*Blepharis pruinosa* Engl. — Acanthaceae
VASC	*Bobartia filiformis* (L.f.) Ker Gawl. — Iridaceae
VASC	*Bobartia gladiata* (L.f.) Ker Gawl. — Iridaceae
VASC	*Bobartia indica* L. — Iridaceae
VASC	*Boerhavia deserticola* Codd — Nyctaginaceae
VASC	*Boerhavia repens* L. — Nyctaginaceae
INSE	*Boisea fulcrata* (Germar, 1838) — Rhopalidae
INSE	*Bolbocoris rufus* (Westwood, 1837) — Pentatomidae
VASC	*Bolusafra bituminosa* (L.) Kuntze — Fabaceae
VASC	*Boophone disticha* (L.f.) Herb. — Amaryllidaceae
VASC	*Boscia albitrunca* (Burch.) Gilg & Gilg-Ben. — Capparaceae
VASC	*Boscia foetida* Schinz — Capparaceae
VASC	*Bothriochloa radicans* (Lehm.) A.Camus — Poaceae
VASC	*Brachiaria brizantha* (A.Rich.) Stapf — Poaceae
VASC	*Brachiaria deflexa* (Schumach.) C.E.Hubb.ex Robyns — Poaceae
VASC	*Brachiaria eruciformis* (J.E.Sm.) Griseb. — Poaceae
VASC	*Brachiaria grossa* Stapf — Poaceae
VASC	*Brachiaria malacodes* (Mez & K.Schum.) Scholz — Poaceae
VASC	*Brachiaria marlothii* (Hack.) Stent — Poaceae
VASC	*Brachiaria nigropedata* (Ficalho & Hiern) Stapf — Poaceae
VASC	*Brachiaria xantholeuca* (Schinz) Stapf — Poaceae
INSE	*Brachycerocoris afer* Stål, 1876 — Pentatomidae
INSE	*Brachycerus* Olivier, 1790 — Curculionidae
VASC	*Brachypodium distachyon* (L.) P.Beauv. — Poaceae
INSE	*Brachythemis lacustris* (Kirby, 1889) — Libellulidae
INSE	*Brachythemis leucosticta* (Burmeister, 1839) — Libellulidae
INSE	*Brachythemis wilsoni* Pinhey, 1952 — Libellulidae
INSE	*Bradinopyga cornuta* Ris, 1911 — Libellulidae
AVES	*Bradornis mariquensis* Smith, 1847 — Muscicapidae
INSE	*Brephidium metophis* (Wallengren, 1860) — Lycaenidae
VASC	*Briza maxima* L. — Poaceae
VASC	*Briza minor* L. — Poaceae
VASC	*Bromus pectinatus* Thunb. — Poaceae
VASC	*Bromus racemosus* L. — Poaceae
INSE	*Brotheolus pugnax* (Breddin, 1913) — Coreidae
INSE	*Brotheolus viridis* (Distant, 1902) — Coreidae
VASC	*Brownanthus arenosus* (Schinz) Ihlenf. & Bittrich — Aizoaceae
VASC	*Brownanthus ciliatus* (Aiton) Schwantes — Aizoaceae
VASC	*Brownanthus corallinus* (Thunb.) Ihlenf. & Bittrich — Aizoaceae
VASC	*Brownanthus kuntzei* (Schinz) Ihlenf. & Bittrich — Aizoaceae
VASC	*Brownanthus pseudoschlichtianus* S.M. Pierce & Gerbaulet — Aizoaceae
VASC	*Brunsvigia bosmaniae* F.M.Leight. — Amaryllidaceae
AVES	*Bubalornis niger* Smith, 1936 — Ploceidae
AVES	*Bubo africanus* (Temminck, 1821) — Strigidae
AVES	*Bubo lacteus* (Temminck, 1821) — Strigidae
AVES	*Bubulcus ibis* (Linnaeus, 1758) — Ardeidae
INSE	*Bucculatrix wittnebeni* Mey, 2004 — Bucculatricidae
LICH	*Buellia concinna* var. *oceanica* Zahlbr. — Physciaceae
LICH	*Buellia distrata* (Nyl.) Zahlbr. — Physciaceae
LICH	*Buellia follmannii Barreno & A. Crespo* — Physciaceae
LICH	*Buellia incrustans* J. Steiner — Physciaceae
LICH	*Buellia parastata* (Nyl.) Zahlbr. — Physciaceae
LICH	*Buellia peregrina* Bungartz & V. Wirth — Physciaceae
LICH	*Buellia pulverea* Coppins & P. James — Physciaceae
LICH	*Buellia sipmanii* V. Wirth & Bungartz — Physciaceae
LICH	*Buellia stellulata* (Taylor) Mudd — Physciaceae
VASC	*Bulbine asphodeloides* (L.) Spreng — Asphodelaceae
VASC	*Bulbine dactylopsoides* G.Will. — Asphodelaceae
VASC	*Bulbine fallax* Poelln. — Asphodelaceae
VASC	*Bulbine frutescens* (L.) Willd. — Asphodelaceae
VASC	*Bulbine hallii* G.Will. — Asphodelaceae
VASC	*Bulbine haworthioides* B.Nord. — Asphodelaceae
VASC	*Bulbine latifolia* (L.f.) Schult. & Schult.f. — Asphodelaceae
VASC	*Bulbine melanovaginata* G. Will. — Asphodelaceae
VASC	*Bulbine mesembryanthoides* Haw. — Asphodelaceae
VASC	*Bulbine praemorsa* (Jacq.) Spreng. — Asphodelaceae
VASC	*Bulbine sedifolia* Schltr. ex Poelln. — Asphodelaceae
VASC	*Bulbine succulenta* Compton — Asphodelaceae
VASC	*Bulbine torta* N.E.Br. — Asphodelaceae
VASC	*Bulbinella triquetra* (L.f.) Kunth — Asphodelaceae
VASC	*Bulbostylis densa* (Wall.) Hand.-Mazz. — Cyperaceae
VASC	*Bulbostylis hispidula* (Vahl) R.W.Haines — Cyperaceae
LICH	*Bulbothrix hypocraea* (Vain.) Hale — Parmeliaceae
AVES	*Buphagus africanus* (Linneaus 1766) — Sturnidae
AVES	*Buphagus erythrorhynchus* (Stanley, 1818) — Sturnidae
VASC	*Burkea africana* Hook. — Fabaceae
AVES	*Buteo buteo vulpinus* (Gloger, 1833) — Accipitridae
AVES	*Buteo rufofuscus* (Forster, 1798) — Accipitridae
INSE	*Byblia ilithya* (Drury, 1773) — Nymphalidae
INSE	*Cacyreus lingeus* (Stoll, 1782) — Lycaenidae
INSE	*Cacyreus marshalli* Butler, 1898 — Lycaenidae
INSE	*Cacyreus virilis* Stempffer, 1936 — Lycaenidae
VASC	*Cadaba aphylla* (Thunb.) Wild — Capparaceae
VASC	*Caesia contorta* (L.f.) T.Durand & Schinz — Hemerocallidaceae
AVES	*Calamonastes fasciolatus* (A.Smith, 1847) — Cisticolidae
AVES	*Calamonastes undosus stierlingi* Reichenow, 1901 — Cisticolidae
AVES	*Calandrella cinerea* (J.F.Gmelin, 1789) — Alaudidae
VASC	*Calicorema capitata* (Maq.) Hook.f. — Amaranthaceae
INSE	*Callidea duodecimpunctata* (Fabricius, 1798) — Scutelleridae
LICH	*Caloplaca alnetorum* Giralt, Nimis & Poelt — Teloschistaceae
LICH	*Caloplaca baueri* (Müll. Arg.) Zahlbr. — Teloschistaceae
LICH	*Caloplaca cinnabarina* (Ach.) Zahlbr. — Teloschistaceae
LICH	*Caloplaca citrina* (Hoffm.) Th. Fr. — Teloschistaceae
LICH	*Caloplaca elegantissima* (Nyl.) Zahlbr. — Teloschistaceae
LICH	*Caloplaca haematodes* (A. Massal.) Zahlbr. — Teloschistaceae
LICH	*Caloplaca holocarpa* (Hoffm.) A.E. Wade — Teloschistaceae
LICH	*Caloplaca* aff. *hungarica* H. Magn. — Teloschistaceae
LICH	*Caloplaca lactea*-group — Teloschistaceae
LICH	*Caloplaca namibensis* Kärnefelt — Teloschistaceae
LICH	*Caloplaca obscurella* (J. Lahm) Th. Fr. — Teloschistaceae

LICH	*Caloplaca rubelliana* (Ach.) Lojka — Teloschistaceae
LICH	*Caloplaca testudinea* V. Wirth & Kärnefelt — Teloschistaceae
LICH	*Caloplaca volkii* V. Wirth & Vězda — Teloschistaceae
VASC	*Calopsis gracilis* (Mast.) H.P.Linder — Restionaceae
VASC	*Calopsis impolita* (Kunth) H.P.Linder — Restionaceae
VASC	*Calopsis viminea* (Rottb.) H.P.Linder — Restionaceae
VASC	*Calostephane divaricata* Benth. — Asteraceae
AVES	*Camaroptera fasciolata* (A.Smith, 1847) — Cisticolidae
INSE	*Camptocoris rostratus* Slater & Ashlock, 1980 — Lygaeidae
VASC	*Camptorrhiza strumosa* (Baker) Oberm. — Colchicaceae
LICH	*Candelaria concolor* (Dicks.) Stein — Candelariaceae
LICH	*Candelariella antennaria* Räsänen — Candelariaceae
LICH	*Candelariella vitellina* (Ehrh.) Müll. Arg. — Candelariaceae
MAM	*Canis mesomelas* Schreber, 1775 — Canidae
VASC	*Cannomois arenicola* H.P.Linder — Restionaceae
LICH	*Canoparmelia epileuca* (Hale) Elix & Hale — Parmeliaceae
AVES	*Caprimulgus pectoralis* Cuvier, 1817 — Caprimulgidae
AVES	*Caprimulgus rufigena* Smith, 1845 — Caprimulgidae
MAM	*Caracal caracal* (Schreber, 1776) — Felidae
INSE	*Carbula abacta* Kirkaldy, 1909 — Pentatomidae
INSE	*Cardephia definiens* (Walker, 1857) — Noctuidae
VASC	*Carissa bispinosa* (L.) Desf. ex Brenan — Apocynaceae
VASC	*Carpacoce vaginellata* Salter — Rubiaceae
VASC	*Carpanthea pomeridiana* (L.) N.E.Br. — Aizoaceae
VASC	*Carpobrotus edulis* (L.) L.Bolus — Aizoaceae
VASC	*Cassine peragua* L. — Celastraceae
VASC	*Cassytha ciliolata* Nees — Lauraceae
VASC	*Catophractes alexandri* D.Don — Bignoniaceae
VASC	*Caulipsolon rapaceum* (Jacq.) Klak — Aizoaceae
INSE	*Caura rufiventris* Germar, 1838 — Pentatomidae
VASC	*Cenchrus biflorus* Roxb. — Poaceae
VASC	*Cenchrus ciliaris* L. — Poaceae
VASC	*Centella caespitosa* Adamson — Apiaceae
VASC	*Centella capensis* (L.) Domin — Apiaceae
VASC	*Centella fusca* (Eckl. & Zeyh.) Adamson — Apiaceae
VASC	*Centella glabrata* L. — Apiaceae
VASC	*Centella macrocarpa* (Rich.) Adamson — Apiaceae
VASC	*Centella tridentata* (L.f.) Drude ex Domin — Apiaceae
INSE	*Centroplax melanosticta* Horváth, 1932 — Coreidae
INSE	*Centroplax meridiana* Villiers, 1950 — Coreidae
VASC	*Centropodia glauca* (Nees) Cope — Poaceae
VASC	*Cephalocroton mollis* Klotzsch — Euphorbiaceae
VASC	*Cephalophyllum ebracteatum* (Schltr. & Diels) Dinter & Schwantes — Aizoaceae
VASC	*Cephalophyllum framesii* L.Bolus — Aizoaceae
VASC	*Cephalophyllum inaequale* L.Bolus — Aizoaceae
VASC	*Cephalophyllum numeesense* H.E.K.Hartmann — Aizoaceae
VASC	*Cephalophyllum pillansii* L.Bolus — Aizoaceae
VASC	*Cephalophyllum rigidum* L.Bolus — Aizoaceae
VASC	*Cephalophyllum spissum* H.E.K.Hartmann — Aizoaceae
VASC	*Cephalophyllum staminodiosum* L.Bolus — Aizoaceae
VASC	*Ceraria fruticulosa* H.Pearson & Stephens — Portulacaceae
VASC	*Ceratandra atrata* (L.) T.Durand & Schinz — Orchidaceae
INSE	*Ceratogomphus pictus* Hagen, 1854 — Gomphidae
INSE	*Ceratogomphus triceraticus* Balinsky, 1963 — Gomphidae
INSE	*Ceratopachys nigricornis* var. *viridis* Linnavuori, 1978 — Coreidae
VASC	*Ceratotheca sesamoides* Endl. — Pedaliaceae
AVES	*Cercomela familiaris* (Stephens, 1826) — Muscicapidae
AVES	*Cercomela schlegelii* (Wahlberg, 1855) — Muscicapidae
AVES	*Cercomela sinuata* (Sundevall, 1858) — Muscicapidae
AVES	*Cercomela tractrac* (Wilkes, 1817) — Muscicapidae
AVES	*Cercotrichas coryphaeus* (Lesson, 1831) — Muscicapidae
AVES	*Cercotrichas leucophrys* (Vieillot, 1817) — Muscicapidae
AVES	*Cercotrichas paena* (A.Smith, 1836) — Muscicapidae
INSE	*Ceriagrion corallinum* Campion, 1914 — Coenagrionidae
INSE	*Ceriagrion glabrum* (Burmeister, 1839) — Coenagrionidae
INSE	*Ceriagrion katamborae* Pinhey, 1961 — Coenagrionidae
INSE	*Ceriagrion suave* Ris, 1921 — Coenagrionidae
INSE	*Ceroctis* Marseul, 1870 — Meloidae
VASC	*Ceropegia nilotica* Kotschy — Apocynaceae
AVES	*Certhilauda albescens* (Lafresnaye, 1839) — Alaudidae
AVES	*Certhilauda burra* (Bangs, 1930) — Alaudidae
AVES	*Certhilauda curvirostris* (Hermann, 1783) — Alaudidae
AVES	*Ceryle rudis* (Linnaeus, 1758) — Alcedinidae
INSE	*Ceutolopha isidis* (Zeller, 1867) — Pyralidae
VASC	*Chaenostoma caeruleum* (L.f.) Kornhall — Scrophulariaceae
LICH	*Chaenothecopsis nana* Tibell — Mycocaliciaceae
VASC	*Chaetobromus involucratus* (Schrad.) Nees — Poaceae
VASC	*Chaetobromus involucratus* subsp. *dregeanus* (Nees) Verboom — Poaceae
INSE	*Chalcostephia flavifrons* Kirby, 1889 — Libellulidae
DIPL	*Chaleponcus limbatus* Attems, 1914 — Odontopygidae
VASC	*Chamaecrista absus* (L.) Irwin & Barneby — Fabaceae
VASC	*Chamaecrista biensis* (Steyaert) Lock — Fabaceae
VASC	*Chamaecrista falcinella* (Oliv.) Lock — Fabaceae
VASC	*Chamaecrista mimosoides* (L.) Greene — Fabaceae
VASC	*Chamaesyce glanduligera* (Pax) Koutnik — Euphorbiaceae
VASC	*Chamarea capensis* (Thunb.) Eckl. & Zeyh. — Apiaceae
VASC	*Chamarea esterhuyseniae* B. L. Burtt — Apiaceae
INSE	*Charaxes achemenes achemenes* (Felder & Rogenhofer, 1867) — Nymphalidae
INSE	*Charaxes jasius saturnus* Butler, 1866 — Nymphalidae
VASC	*Chascanum garipense* E.Mey. — Verbenaceae
VASC	*Chascanum pinnatifidum* (L.f.) E.Mey. — Verbenaceae
VASC	*Chascanum pinnatifidum* (L.f.) E.Mey. var. *pinnatifidum* — Verbenaceae
VASC	*Chascanum pumilum* E.Mey. — Verbenaceae
VASC	*Cheilanthes capensis* (Thunb.) Sw. — Aizoaceae
VASC	*Cheilanthes dinteri* Brause — Aizoaceae
VASC	*Cheilanthes marlothii* (Hieron.) Schelpe — Aizoaceae
VASC	*Cheilanthes robusta* (Kunze) R.M.Tryon — Aizoaceae
VASC	*Cheiridopsis denticulata* (Haw.) N.E.Br. — Aizoaceae
VASC	*Cheiridopsis imitans* L.Bolus — Aizoaceae
VASC	*Cheiridopsis namaquensis* (Sond.) H.E.K.Hartmann — Aizoaceae
VASC	*Cheiridopsis robusta* (Haw.) N.E.Br. — Aizoaceae
VASC	*Chenopodiopsis hirta* (L.f.) Hilliard — Scrophulariaceae
VASC	*Chenopodium album* L. — Chenopodiaceae
VASC	*Chenopodium amboanum* (Murr) Aellen — Chenopodiaceae
VASC	*Chenopodium murale* L. var. *murale* — Chenopodiaceae
VASC	*Chenopodium pumilio* R.Br. — Chenopodiaceae
REPT	*Chersina angulata* (Schweigger, 1812) — Testudinidae
AVES	*Chersomanes albofasciata* (Lafresnaye, 1836) — Alaudidae
INSE	*Chilades trochylus* (Freyer, 1843) — Lycaenidae
VASC	*Chironia linoides* L. — Gentianaceae
VASC	*Chloris virgata* Sw. — Poaceae
INSE	*Chlorolestes conspicuus* Selys, 1862 — Synlestidae
INSE	*Chlorolestes fasciatus* (Burmeister, 1839) — Synlestidae
INSE	*Chlorolestes tessellatus* (Burmeister, 1839) — Synlestidae
INSE	*Chlorolestes umbratus* Hagen in Selys, 1862 — Synlestidae
VASC	*Chlorophytum calyptrocarpum* (Baker) Kativu — Anthericaceae
VASC	*Chlorophytum crassinerve* (Baker) Oberm. — Anthericaceae
VASC	*Chlorophytum galpinii* (Baker) Kativu — Anthericaceae
VASC	*Chlorophytum galpinii* var. *matabelense* (Baker) Kativu — Anthericaceae
VASC	*Chlorophytum rangei* (Engl. & K.Krause) Nordal — Anthericaceae
VASC	*Chlorophytum undulatum* (Jacq.) Oberm. — Anthericaceae
VASC	*Chondropetalum nudum* Rottb. — Restionaceae
VASC	*Chrysanthemoides incana* (Burm.f.) Norl. — Asteraceae
VASC	*Chrysanthemoides monilifera* (L.) Norl. — Asteraceae
INSE	*Chrysis grootdermensis* Koch, 2006 — Chrysididae
AVES	*Chrysococcyx caprius* (Boddaert, 1783) — Cuculidae
VASC	*Chrysocoma ciliata* L. — Asteraceae
INSE	*Chrysoritis pan* (Pennington, 1862) — Lycaenidae
INSE	*Chrysoritis thysbe thysbe* (Linnaeus, 1764) — Lycaenidae
LICH	*Chrysothrix candelaris* (L.) J.R. Laundon — Chrysotrichaceae
AVES	*Ciconia abdimii* Lichtenstein, 1823 — Ciconiidae
INSE	*Cigaritis namaqua* (Trimen, 1874) — Lycaenidae
INSE	*Cigaritis phanes* (Trimen, 1873) — Lycaenidae
VASC	*Cineraria canescens* J.C.Wendl. ex Link — Asteraceae
AVES	*Cinnyris fuscus* (Vieilott, 1819) — Nectariniidae
AVES	*Circaetus cinereus* Vieilott, 1818 — Accipitridae
AVES	*Circaetus pectoralis* A.Smith, 1829 — Accipitridae
VASC	*Cissampelos capensis* L.f. — Menispermaceae
AVES	*Cisticola aridulus* Witherby, 1900 — Cisticolidae
AVES	*Cisticola chiniana* (A.Smith, 1843) — Cisticolidae
AVES	*Cisticola subruficapillus* (A.Smith, 1843) — Cisticolidae
AVES	*Cisticola textrix* (Vieillot, 1817) — Cisticolidae

VASC	*Citrullus ecirrhosus* Cogn. — Cucurbitaceae
VASC	*Citrullus lanatus* (Thunb.) Matsum. & Nakai — Cucurbitaceae
VASC	*Citrullus rehmii* De Winter — Cucurbitaceae
LICH	*Cladonia cervicornis* (Ach.) Flot. — Cladoniaceae
LICH	*Cladonia symphycarpa* (Flörke) Fr. — Cladoniaceae
VASC	*Cladoraphis cyperoides* (Thunb.) S.M.Phillips — Poaceae
VASC	*Cladoraphis spinosa* (L.f.) S.M.Phillips — Poaceae
INSE	*Clavigralla horrida* (Germar, 1840) — Coreidae
VASC	*Cleome angustifolia* Forssk. — Capparaceae
VASC	*Cleome angustifolia* subsp. *diandra* (Burch.) Kers — Capparaceae
VASC	*Cleome carnosa* (Pax) Gilg & Gilg-Ben. — Capparaceae
VASC	*Cleome elegantissima* Briq. — Capparaceae
VASC	*Cleome foliosa* Hook f. — Capparaceae
VASC	*Cleome gynandra* L. — Capparaceae
VASC	*Cleome hirta* (Klotzsch) Oliv. — Capparaceae
VASC	*Cleome kalachariensis* (Shinz) Gilg & Gilg-Ben. — Capparaceae
VASC	*Cleome monophylla* L. — Capparaceae
VASC	*Cleome rubella* Burch. — Capparaceae
VASC	*Cleome semitetrandra* Sond. — Capparaceae
VASC	*Cleome suffruticosa* Schinz — Capparaceae
VASC	*Cleretum papulosum* (L.f.) L.Bolus subsp. *papulosum* — Aizoaceae
VASC	*Clerodendrum ternatum* Schinz — Lamiaceae
INSE	*Cletomorpha lituripennis* Stål, 1855 — Coreidae
INSE	*Cletus binotatulus* (Stål, 1858) — Coreidae
INSE	*Cletus ferruginosus* Stål, 1873 — Coreidae
INSE	*Cletus pusillus* (Dallas, 1852) — Coreidae
INSE	*Cletus spicatus* Hesse, 1925 — Coreidae
VASC	*Cliffortia dodecandra* Weim. — Rosaceae
VASC	*Cliffortia filifolia* L.f. — Rosaceae
VASC	*Cliffortia juniperina* L.f. — Rosaceae
VASC	*Cliffortia marginata* Eckl. & Zeyh. — Rosaceae
VASC	*Cliffortia ruscifolia* L. — Rosaceae
VASC	*Cliffortia subsetacea* (Eckl. & Zeih.) Diels ex Bolus & Wolley-Dod — Rosaceae
VASC	*Coccinia rehmannii* Cogn. — Cucurbitaceae
VASC	*Coccinia sessilifolia* (Sond.) Cogn. — Cucurbitaceae
INSE	*Cochlochila austroafricana* Duarte Rodrigues, 1982 — Tingidae
VASC	*Codon royenii* L. — Boraginaceae
INSE	*Coeliades forestan forestan* (Stoll, 1782) — Hesperidae
INSE	*Coeliades pisistratus* (Fabricius, 1793) — Hesperiidae
INSE	*Coenobasis argentilinea* (Aurivillius, 1899) — Limacodidae
INSE	*Coenyropsis natalii natalii* (Boisduval, 1847) — Satyridae
AVES	*Colius colius* (Linnaeus, 1766) — Coliidae
LICH	*Collema coccophorum* Tuck. — Collemataceae
LICH	*Collema crispum* (Hudson) Weber ex F.H.Wigg. — Collemataceae
LICH	*Collema occultatum* Bagl. — Collemataceae
LICH	*Collema tenax* (Sw.) Ach. — Collemataceae
LICH	*Collema texanum* Tuck. — Collemataceae
VASC	*Colophospermum mopane* (J.Kirk ex Benth) J.Kirk ex J.éonard — Fabaceae
INSE	*Colotis agoye bowkeri* (Trimen, 1883) — Pieridae
INSE	*Colotis antevippe gavisa* (Wallengren, 1857) — Pieridae
INSE	*Colotis celimene pholoe* (Wallengren, 1860) — Pieridae
INSE	*Colotis doubledayi flavulus* Henning et al. 1997 — Pieridae
INSE	*Colotis eris eris* (Klug, 1829) — Pieridae
INSE	*Colotis evagore antigone* (Boisduval, 1839) — Pieridae
INSE	*Colotis evenina evenina* (Wallengren, 1857) — Pieridae
INSE	*Colotis evippe omphale* (Godart, 1819) — Pieridae
INSE	*Colotis ione* (Godart, 1819) — Pieridae
INSE	*Colotis lais* (Butler, 1876) — Pieridae
INSE	*Colotis pallene* (Hopffer, 1855) — Pieridae
INSE	*Colotis regina* (Trimen, 1863) — Pieridae
INSE	*Colotis subfasciatus subfasciatus* (Swainson, 1832) — Pieridae
INSE	*Colotis vesta mutans* (Butler, 1877) — Pieridae
AVES	*Columba guinea* (Linnaeus, 1758) — Columbidae
VASC	*Combretum apiculatum* Sond. — Combretaceae
VASC	*Combretum collinum* Fresen. — Combretaceae
VASC	*Combretum engleri* Schinz — Combretaceae
VASC	*Combretum hereroense* Schinz — Combretaceae
VASC	*Combretum psidioides* Welw. — Combretaceae
VASC	*Combretum tenuipetiolatum* Wickens — Combretaceae
VASC	*Combretum zeyheri* Sond. — Combretaceae
VASC	*Commelina africana* L. — Commelinaceae
VASC	*Commelina africana* var. *krebsiana* (Kunth) C.B.Clarke — Commelinaceae
VASC	*Commelina aspera* Benth. — Commelinaceae
VASC	*Commelina benghalensis* L. — Commelinaceae
VASC	*Commelina erecta* L. — Commelinaceae
VASC	*Commelina forskaolii* Vahl — Commelinaceae
VASC	*Commelina livingstonii* C.B.Clarke — Commelinaceae
VASC	*Commelina subulata* Roth — Commelinaceae
VASC	*Commiphora africana* (A.Rich.) Engl. — Burseraceae
VASC	*Commiphora angolensis* Engl. — Burseraceae
VASC	*Commiphora glandulosa* Schinz — Burseraceae
VASC	*Commiphora glaucescens* Engl. — Burseraceae
VASC	*Commiphora pyracanthoides* Engl. — Burseraceae
VASC	*Commiphora saxicola* Engl. — Burseraceae
VASC	*Commiphora tenuipetiolata* Engl. — Burseraceae
VASC	*Conicosia elongata* (Haw.) N.E.Br. — Aizoaceae
VASC	*Conicosia pugioniformis* (L.) N.E.Br. — Aizoaceae
VASC	*Conicosia pugioniformis* subsp. *alborosea* (L.Bolus) Ihlenf. & Gerbaulet — Aizoaceae
VASC	*Conophytum bilobum* (Marloth) N.E.Br. — Aizoaceae
VASC	*Conophytum calculus* (A.Berger) N.E.Br. subsp. *calculus* — Aizoaceae
VASC	*Conophytum calculus* subsp. *vanzylii* (Lavis) S.A.Hammer — Aizoaceae
VASC	*Conophytum gratum* (N.E.Br.) N.E.Br. — Aizoaceae
VASC	*Conophytum minutum* (Haw.) N.E.Br. var. *minutum* — Aizoaceae
VASC	*Conophytum minutum* var. *pearsonii* (N.E.Br.) Broom — Aizoaceae
VASC	*Conophytum pellucidum* var. *terricolor* (Tischer) Littlew. ex S.A.Hammer — Aizoaceae
VASC	*Conophytum subfenestratum* Schwantes — Aizoaceae
VASC	*Conophytum uviforme* (Haw.) N.E.Br. — Aizoaceae
VASC	*Convolvulus argillicola* Pilg. — Convolvulaceae
VASC	*Convolvulus capensis* Burm.f. — Convolvulaceae
VASC	*Convolvulus sagittatus* Thunb. — Convolvulaceae
INSE	*Coponia capensis* Fabricius, 1781 — Pentatomidae
AVES	*Coracias caudata* Linnaeus, 1766 — Coraciidae
AVES	*Coracias naevia* Daudin, 1800 — Coraciidae
VASC	*Corallocarpus bainesii* (Hook. f.) A.Meeuse — Cucurbitaceae
VASC	*Corallocarpus dissectus* Cogn. — Cucurbitaceae
VASC	*Corallocarpus schinzii* Cogn. — Cucurbitaceae
VASC	*Corallocarpus triangularis* Cogn. — Cucurbitaceae
VASC	*Corallocarpus welwitschii* (Naudin) Hook.f. ex Welw. — Cucurbitaceae
INSE	*Coranus carbonarius* Stål, 1855 — Reduviidae
VASC	*Corbichonia decumbens* (Forssk.) Exell — Molluginaceae
VASC	*Corchorus asplenifolius* Burch. — Tiliaceae
VASC	*Corchorus schimperi* Cufod. — Tiliaceae
VASC	*Corchorus tridens* L. — Tiliaceae
VASC	*Cordia monoica* Roxb. — Boraginaceae
AVES	*Corvus albus* Müller, 1776 — Corvidae
AVES	*Corvus capensis* M.H.K. Lichtenstein, 1823 — Corvidae
VASC	*Corycium orobanchoides* (L.f.) Sw. — Orchidaceae
VASC	*Corymbium africanum* L. — Asteraceae
VASC	*Corymbium africanum* subsp. *scabridum* (P.J.Bergius) Weitz — Asteraceae
VASC	*Corymbium africanum* var. *scabridum* (P.J.Bergius) Weitz — Asteraceae
VASC	*Corymbium glabrum* L. — Asteraceae
AVES	*Corythaixoides concolor* (A.Smith, 1833) — Musophagidae
INSE	*Cosmolestes pictus* (Klug, 1830) — Reduviidae
VASC	*Cotula anthemoides* L. — Asteraceae
VASC	*Cotula barbata* DC. — Asteraceae
VASC	*Cotula coronopifolia* L. — Asteraceae
VASC	*Cotula duckittiae* (L.Bolus) K.Bremer & Humphries — Asteraceae
VASC	*Cotula filifolia* Thunb. — Asteraceae
VASC	*Cotula leptalea* DC. — Asteraceae
VASC	*Cotula microglossa* (DC.) O.Hoffm. & Kuntze ex Kuntze — Asteraceae
VASC	*Cotula turbinata* L. — Asteraceae
AVES	*Coturnix coturnix* (Linnaeus, 1758) — Phasianidae

VASC	*Cotyledon cuneata* Thunb. — Crassulaceae
VASC	*Cotyledon orbiculata* L. — Crassulaceae
VASC	*Cotyledon orbiculata* L. var. *orbiculata* — Crassulaceae
VASC	*Cotyledon papillaris* L.f. — Crassulaceae
VASC	*Courtoisina assimilis* (Steud.) Maquet — Cyperaceae
VASC	*Courtoisina cyperoides* (Roxb.) Sojak — Cyperaceae
VASC	*Crassula atropurpurea* (Haw.) D.Dietr. — Crassulaceae
VASC	*Crassula brevifolia* Harv. subsp. *brevifolia* — Crassulaceae
VASC	*Crassula capitella* Thunb. subsp. *thyrsiflora* (Thunb.) Tölken — Crassulaceae
VASC	*Crassula ciliata* L. — Crassulaceae
VASC	*Crassula clavata* N.E.Br. — Crassulaceae
VASC	*Crassula columnaris* Thunb. subsp. *columnaris* — Crassulaceae
VASC	*Crassula columnaris* subsp. *prolifera* Friedrich — Crassulaceae
VASC	*Crassula corallina* Thunb. — Crassulaceae
VASC	*Crassula cotyledonis* Thunb. — Crassulaceae
VASC	*Crassula deceptor* Schönland & Baker f. — Crassulaceae
VASC	*Crassula dichotoma* L. — Crassulaceae
VASC	*Crassula elegans* Schönland & Baker f. — Crassulaceae
VASC	*Crassula expansa* Dryand. subsp. *expansa* — Crassulaceae
VASC	*Crassula expansa* subsp. *pyrifolia* (Compton) Tölken — Crassulaceae
VASC	*Crassula fascicularis* Lam. — Crassulaceae
VASC	*Crassula fusca* Herre — Crassulaceae
VASC	*Crassula garibina* Marloth & Schönland — Crassulaceae
VASC	*Crassula glomerata* P.J.Bergius — Crassulaceae
VASC	*Crassula grisea* Schönland — Crassulaceae
VASC	*Crassula hemisphaerica* Thunb. — Crassulaceae
VASC	*Crassula hirsuta* Schönland & Baker f. — Crassulaceae
VASC	*Crassula hirtipes* Harv. — Crassulaceae
VASC	*Crassula macowaniana* Schönland & Baker f. — Crassulaceae
VASC	*Crassula muscosa* L. — Crassulaceae
VASC	*Crassula muscosa* L. var. *muscosa* — Crassulaceae
VASC	*Crassula muscosa* var. *obtusifolia* (Harv.) G.D.Rowley — Crassulaceae
VASC	*Crassula namaquensis* Schönland & Baker f. — Crassulaceae
VASC	*Crassula natans* Thunb. — Crassulaceae
VASC	*Crassula nudicaulis* L. — Crassulaceae
VASC	*Crassula pseudohemisphaerica* Friedrich — Crassulaceae
VASC	*Crassula pubescens* Thunb. — Crassulaceae
VASC	*Crassula pyramidalis* Thunb. — Crassulaceae
VASC	*Crassula rudolfii* Schönland & Baker f. — Crassulaceae
VASC	*Crassula rupestris* Thunb. — Crassulaceae
VASC	*Crassula sericea* Schönland var. *sericea* — Crassulaceae
VASC	*Crassula strigosa* L. — Crassulaceae
VASC	*Crassula subacaulis* Schönland & Baker f. — Crassulaceae
VASC	*Crassula subacaulis* subsp. *erosula* (N.E.Br.) Tölken — Crassulaceae
VASC	*Crassula subaphylla* (Eckl. & Zeyh.) Harv. var. *subaphylla* — Crassulaceae
VASC	*Crassula subaphylla* var. *virgata* (Harv.) Tölken — Crassulaceae
VASC	*Crassula subulata* L. — Crassulaceae
VASC	*Crassula tetragona* subsp. *rudis* (Schönland & Baker f.) Tölken — Crassulaceae
VASC	*Crassula thunbergiana* Schult. — Crassulaceae
VASC	*Crassula tomentosa* Thunb. — Crassulaceae
VASC	*Crassula umbellata* Thunb. — Crassulaceae
VASC	*Crassula vaillantii* (Willd.) Roth — Crassulaceae
VASC	*Crassula whiteheadii* Harv. — Crassulaceae
INSE	*Crematogaster* Lund, 1831 — Formicidae
INSE	*Crenigomphus cornutus* Pinhey, 1956 — Gomphidae
INSE	*Crenigomphus hartmanni* (Förster, 1898) — Gomphidae
INSE	*Crenigomphus kavangoensis* Suhling & Marais, 2010 — Gomphidae
VASC	*Crinum graminicola* I.Verd. — Amaryllidaceae
VASC	*Crinum rautanenianum* Schinz — Amaryllidaceae
INSE	*Crocothemis divisa* Baumann, 1898 — Libellulidae
INSE	*Crocothemis erythraea* (Brullé, 1832) — Libellulidae
INSE	*Crocothemis sanguinolenta* (Burmeister, 1839) — Libellulidae
VASC	*Crossyne guttata* (L.) D.Müll.-Doblies & U.Müll.-Doblies — Amaryllidaceae
VASC	*Crotalaria argyraea* Welw. ex Baker — Fabaceae
VASC	*Crotalaria barkae* Schweinf. — Fabaceae
VASC	*Crotalaria barnabassii* Dinter ex Baker f. — Fabaceae
VASC	*Crotalaria dinteri* Schinz — Fabaceae
VASC	*Crotalaria flavicarinata* Baker f. — Fabaceae
VASC	*Crotalaria heidmannii* Schinz — Fabaceae
VASC	*Crotalaria humilis* Eckl. & Zeyh. — Fabaceae
VASC	*Crotalaria meyeriana* Steud. — Fabaceae
VASC	*Crotalaria pisicarpa* Welw. ex Baker — Fabaceae
VASC	*Crotalaria platysepala* Harv. — Fabaceae
VASC	*Crotalaria podocarpa* DC. — Fabaceae
VASC	*Crotalaria spartioides* DC. — Fabaceae
VASC	*Crotalaria sphaerocarpa* Perr. ex DC. — Fabaceae
VASC	*Croton gratissimus* Burch. — Euphorbiaceae
VASC	*Croton gratissimus* Burch. var. *gratissimus* — Euphorbiaceae
VASC	*Cryptolepis decidua* (Planch. ex Hook.f. & Benth.) N.E.Br. — Apocynaceae
VASC	*Cryptolepis oblongifolia* (Meisn.) Schltr. — Apocynaceae
INSE	*Ctenusa varians* (Wallengren, 1863) — Noctuidae
AVES	*Cuculus gularis* Stephens, 1815 — Musophagidae
VASC	*Cucumis africanus* L.f. — Cucurbitaceae
VASC	*Cucumis anguria* var. *longaculeatus* J.H.Kirkbr. — Cucurbitaceae
VASC	*Cucumis humifructus* Stent — Cucurbitaceae
VASC	*Cucumis kalahariensis* A.Meeuse — Cucurbitaceae
VASC	*Cucumis myriocarpus* Naudin — Cucurbitaceae
VASC	*Cucumis rigidus* E.Mey. ex Sond. — Cucurbitaceae
VASC	*Cucumis sagittatus* Peyr. — Cucurbitaceae
VASC	*Cullen tomentosum* (Thunb.) J.W.Grimes — Fabaceae
VASC	*Cullumia squarrosa* (L.) R.Br. — Asteraceae
VASC	*Cuscuta nitida* Choisy — Convolvulaceae
VASC	*Cyamopsis senegalensis* Guill. & Perr. — Fabaceae
VASC	*Cyamopsis serrata* Schinz — Fabaceae
VASC	*Cyanella hyacinthoides* L. — Tecophilaeaceae
VASC	*Cyanella lutea* L.f. — Tecophilaeaceae
VASC	*Cyclopia genistoides* (L.) R.Br. — Fabaceae
VASC	*Cymbopogon pospischilii* (K.Schum.) Hubb. — Poaceae
VASC	*Cynanchum orangeanum* (Schltr.) N.E.Br. — Apocynaceae
MAM	*Cynictis penicillata* (G.[Baron] Cuvier, 1829) — Herpestidae
VASC	*Cynodon dactylon* (L.) Pers. — Poaceae
VASC	*Cyperus albostriatus* Schrad. — Cyperaceae
VASC	*Cyperus amabilis* Vahl — Cyperaceae
VASC	*Cyperus chersinus* (N.E.Br.) Kük. — Cyperaceae
VASC	*Cyperus compressus* L. — Cyperaceae
VASC	*Cyperus cuspidatus* Kunth — Cyperaceae
VASC	*Cyperus denudatus* L.f. — Cyperaceae
VASC	*Cyperus difformis* L. — Cyperaceae
VASC	*Cyperus esculentus* L. — Cyperaceae
VASC	*Cyperus fulgens* C.B.Clarke — Cyperaceae
VASC	*Cyperus margaritaceus* Vahl — Cyperaceae
VASC	*Cyperus marginatus* Thunb. — Cyperaceae
VASC	*Cyperus procerus* Rottb. — Cyperaceae
VASC	*Cyperus schinzii* Boeck. — Cyperaceae
VASC	*Cyperus turrillii* Kük. — Cyperaceae
VASC	*Cyphia bulbosa* (L.) P.J.Bergius — Lobeliaceae
VASC	*Cyphia crenata* (Thunb.) C.Presl. — Lobeliaceae
VASC	*Cyphia heterophylla* (C.Presl.) Eckl. & Zeyh. — Lobeliaceae
VASC	*Cyphia incisa* (Thunb.) Willd. — Lobeliaceae
VASC	*Cyphia longiflora* Schltr. — Lobeliaceae
VASC	*Cyphia phyteuma* (L.) Willd. — Lobeliaceae
VASC	*Cyphia volubilis* (Burm.f.) Willd. — Lobeliaceae
VASC	*Cyphostemma congestum* (Baker) Desc. ex Wild & R.B.Drumm. — Vitaceae
VASC	*Cyphostemma hereroense* (Schinz) Desc. ex Wild & R.B.Drumm. — Vitaceae
VASC	*Cyphostemma omburense* (Gilg & M.Brandt) Desc. — Vitaceae
VASC	*Cyphostemma sandersonii* (Harv.) Desc. — Vitaceae
VASC	*Cysticapnos vesicaria* (L.) Fedde — Fumariaceae
VASC	*Dactyliandra welwitschii* Hook.f. — Cucurbitaceae
VASC	*Dactyloctenium aegyptium* (L.) Willd. — Poaceae
VASC	*Dactyloctenium giganteum* Fisher & Schweick. — Poaceae
VASC	*Dactylopsis digitata* (Aiton) N.E.Br. — Aizoaceae
INSE	*Danaus chrysippus aegyptius* (von Schreber, 1759) — Nymphalidae
VASC	*Datura ferox* L. — Solanaceae
VASC	*Delosperma crassum* L.Bolus — Aizoaceae
INSE	*Deltophora typica* Sattler, 1979 — Gelechiidae
AVES	*Dendropicos fuscescens* (Vieillot, 1818) — Picidae
AVES	*Dendropicos namaquus* (Lichtenstein, 1793) — Picidae

INSE	*Dermatinus limbifer* Stål, 1855 — Pyrrhocoridae
MAM	*Desmodillus auricularis* (A.Smith, 1834) — Muridae
INSE	*Deudorix antalus* (Hopffer, 1855) — Lycaenidae
VASC	*Dialium engleranum* Henriq. — Fabaceae
VASC	*Diandrochloa pusilla* (Hack.) De Winter — Poaceae
VASC	*Dianthus holopetalus* Turcz. — Caryophyllaceae
VASC	*Dianthus namaensis* Schinz — Caryophyllaceae
VASC	*Diascia batteniana* K.E.Steiner — Scrophulariaceae
VASC	*Diascia dissimulans* Hilliard & B.L.Burtt — Scrophulariaceae
VASC	*Diascia elongata* Benth. — Scrophulariaceae
VASC	*Diascia namaquensis* Hiern — Scrophulariaceae
VASC	*Diascia rudolphii* Hiern — Scrophulariaceae
VASC	*Diastella divaricata* (P.J.Bergius) Rourke subsp. *divaricata* — Proteaceae
VASC	*Diastella proteoides* (L.) Druce — Proteaceae
MAM	*Diceros bicornis* (Linnaeus, 1758) — Rhinocerotidae
VASC	*Dicerothamnus rhinocerotis* (L.f.) Koekemoer — Asteraceae
VASC	*Dichanthium annulatum* var. *papillosum* (A.Rich) de Wet & Harlan — Poaceae
VASC	*Dichapetalum cymosum* (Hook.) Engl. — Cunoniaceae
VASC	*Dichapetalum rhodesicum* Sprague & Hutch. — Cunoniaceae
VASC	*Dichrostachys cinerea* (L.) Wight & Arn. — Fabaceae
VASC	*Dicliptera capensis* Nees — Acanthaceae
VASC	*Dicoma capensis* Less. — Asteraceae
VASC	*Dicoma macrocephala* DC. — Asteraceae
VASC	*Dicoma schinzii* O.Hoffm. — Asteraceae
VASC	*Dicoma tomentosa* Cass. — Asteraceae
INSE	*Dicranocephalus caffer* (Dallas, 1852) — Stenocephalidae
INSE	*Dicranocephalus pseudotestaceus* Landsbury, 1965 — Stenocephalidae
INSE	*Dicranocephalus schmitzi* Göllner-Scheiding, 1996 — Stenocephalidae
VASC	*Dicrocaulon brevifolium* N.E.Br. — Aizoaceae
VASC	*Dicrocaulon humile* N.E.Br. — Aizoaceae
VASC	*Dicrocaulon ramulosum* (L.Bolus) Ihlenf. — Aizoaceae
AVES	*Dicrurus adsimilis* (Bechstein, 1794) — Dicruridae
VASC	*Didelta carnosa* (L.f.) Aiton — Asteraceae
VASC	*Didelta spinosa* (L.f.) Aiton — Asteraceae
INSE	*Dieuches armatipes* (Walker, 1872) — Rhyparochromidae
INSE	*Dieuches herero* Breddin, 1913 — Rhyparochromidae
VASC	*Digitaria eriantha* Steud. — Poaceae
VASC	*Digitaria gayana* (Kunth) Stapf ex A.Chev. — Poaceae
VASC	*Digitaria seriata* Stapf — Poaceae
VASC	*Digitaria velutina* (Forssk.) P.Beauv. — Poaceae
VASC	*Dilatris pillansii* W.F.Barker — Haemodoraceae
VASC	*Dimorphotheca nudicaulis* (L.) DC. — Asteraceae
VASC	*Dimorphotheca pluvialis* (L.) Moench — Asteraceae
VASC	*Dimorphotheca polyptera* DC. — Asteraceae
VASC	*Dimorphotheca sinuata* DC. — Asteraceae
VASC	*Dimorphotheca tragus* (Aiton) B.Nord. — Asteraceae
VASC	*Dioscorea quartiniana* A.Rich. — Dioscoreaceae
VASC	*Diosma acmaeophylla* Eckl. & Zeyh. — Rutaceae
VASC	*Diosma aspalathoides* Lam. — Rutaceae
VASC	*Diosma dichotoma* P.J.Bergius — Rutaceae
VASC	*Diosma oppositifolia* L. — Rutaceae
VASC	*Diosma pedicellata* I.Williams — Rutaceae
VASC	*Diospyros austro-africana* De Winter — Ebenaceae
VASC	*Diospyros chamaethamnus* Dinter ex Mildbr. — Ebenaceae
VASC	*Diospyros glabra* (L.) De Winter — Ebenaceae
VASC	*Diospyros lycioides* Desf. — Ebenaceae
VASC	*Diospyros ramulosa* (E.Mey.ex A.DC.) De Winter — Ebenaceae
VASC	*Dipcadi bakerianum* Bolus — Hyacinthaceae
VASC	*Dipcadi crispum* Baker — Hyacinthaceae
VASC	*Dipcadi longifolium* (Lindl.) Baker — Hyacinthaceae
VASC	*Dipcadi marlothii* Engl. — Hyacinthaceae
VASC	*Dipcadi rigidifolium* (Lindl.) Baker — Hyacinthaceae
VASC	*Dipcadi viride* (L.) Moench — Hyacinthaceae
INSE	*Diplacodes deminuta* Lieftinck, 1969 — Libellulidae
INSE	*Diplacodes lefebvrii* (Rambur, 1842) — Libellulidae
INSE	*Diplacodes luminans* (Karsch, 1893) — Libellulidae
LICH	*Diploicia canescens* (Dicks.) A. Massal. — Physciaceae
VASC	*Diplorhynchus condylocarpon* (Müll. Arg.) Pichon — Apocynaceae
LICH	*Diploschistes aeneus* (Müll. Arg.) Lumbsch — Thelotremataceae
LICH	*Diploschistes austroafricanus* Guderley & Lumbsch — Thelotremataceae
LICH	*Diploschistes euganeus* (A. Massal.) Zahlbr. — Thelotremataceae
LICH	*Diploschistes hensseniae* Lumbsch & Elix — Thelotremataceae
VASC	*Diplosoma luckhoffii* (L.Bolus) Schwantes ex Ihlenf. — Aizoaceae
LICH	*Dirinaria complicata* D.D. Awasthi — Physciaceae
VASC	*Disa bracteata* Sw. — Orchidaceae
VASC	*Disa spathulata* (L.f.) Sw. — Orchidaceae
VASC	*Disa tenella* (L.f.) Sw. — Orchidaceae
VASC	*Disa tenuifolia* Sw. — Orchidaceae
VASC	*Dischisma capitatum* (Thunb.) Choisy — Scrophulariaceae
VASC	*Dischisma ciliatum* (P.J.Bergius) Choisy — Scrophulariaceae
VASC	*Dischisma spicatum* (Thunb.) Choisy — Scrophulariaceae
VASC	*Disparago ericoides* (P.J.Bergius) Gaertn. — Asteraceae
VASC	*Disperis capensis* (L.f.) Sw. var. *capensis* — Orchidaceae
VASC	*Disperis circumflexa* (L.) T.Durand & Schinz — Orchidaceae
VASC	*Disperis cucullata* Sw. — Orchidaceae
VASC	*Disperis villosa* (L.f.) Sw. — Orchidaceae
VASC	*Dolichos junodii* (Harms) Verdc. — Fabaceae
VASC	*Dolichos linearis* E.Mey. — Fabaceae
DIPL	*Doratogonus rugifrons* (Attems, 1922) — Spirostreptidae
VASC	*Dorotheanthus bellidiformis* (Burman) N.E.Br. — Aizoaceae
VASC	*Dorotheanthus bellidiformis* subsp. *hestermalensis* Ihlenf. & Struck — Aizoaceae
VASC	*Dovyalis caffra* (Hook.f. & Harv.) Hook. f. — Flacourtiaceae
VASC	*Drimia convallarioides* (L.f.) J.C.Manning & Goldblatt — Hyacinthaceae
VASC	*Drimia elata* Jacq. — Hyacinthaceae
VASC	*Drimia filifolia* (Jacq.) J.C.Manning & Goldblatt. — Hyacinthaceae
VASC	*Drimia nana* (Snijman) J.C.Manning & Goldblatt — Hyacinthaceae
VASC	*Drimia platyphylla* (B.Nord.) J.C.Manning & Goldblatt — Hyacinthaceae
VASC	*Drimia sanguinea* (Schinz) Jessop — Hyacinthaceae
VASC	*Drosanthemum albens* L.Bolus — Aizoaceae
VASC	*Drosanthemum curtophyllum* L.Bolus — Aizoaceae
VASC	*Drosanthemum deciduum* H.E.K.Hartmann & Bruckmann — Aizoaceae
VASC	*Drosanthemum diversifolium* L.Bolus — Aizoaceae
VASC	*Drosanthemum floribundum* (Haw.) Schwantes — Aizoaceae
VASC	*Drosanthemum glabrescens* L.Bolus — Aizoaceae
VASC	*Drosanthemum globosum* L.Bolus — Aizoaceae
VASC	*Drosanthemum hispidum* (L.) Schwantes — Aizoaceae
VASC	*Drosanthemum inornatum* (L.Bolus) L.Bolus — Aizoaceae
VASC	*Drosanthemum luederitzii* (Engl.) Schwantes — Aizoaceae
VASC	*Drosanthemum muirii* L.Bolus — Aizoaceae
VASC	*Drosanthemum pulverulentum* (Haw.) Schwantes — Aizoaceae
VASC	*Drosanthemum ramosissimum* (Schlechter) L.Bolus — Aizoaceae
VASC	*Drosanthemum schoenlandianum* (Schltr.) L.Bolus — Aizoaceae
VASC	*Drosera alba* E.Phillips — Droseraceae
VASC	*Drosera cistiflora* L. — Droseraceae
VASC	*Drosera pauciflora* Banks ex DC. — Droseraceae
VASC	*Drosera trinervia* Spreng. — Droseraceae
VASC	*Duosperma crenatum* (Lindau) P.G.Mey. — Acanthaceae
VASC	*Duvalia caespitosa* (Masson) Haw. — Apocynaceae
VASC	*Dyerophytum africanum* (Lam.) Kuntze — Plumbaginaceae
VASC	*Eberlanzia cyathiformis* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Eberlanzia ebracteata* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Eberlanzia schneideriana* (A.Berger) H.E.K.Hartmann — Aizoaceae
INSE	*Ecchlorolestes nylephtha* Barnard, 1937 — Synlestidae
INSE	*Ecchlorolestes peringueyi* (Ris, 1921) — Synlestidae
VASC	*Echinochloa colona* (L.) Link — Poaceae
VASC	*Echinochloa crus-galli* (L.) P.Beauv. — Poaceae
VASC	*Echinochloa holubii* (Stapf) Stapf — Poaceae
VASC	*Echinochloa stagnina* (Retz.) P.Beauv. — Poaceae
VASC	*Echiostachys incanus* (Thunb.) Levyns — Boraginaceae
INSE	*Ectochela nigrilineata* Gaede, 1915 — Noctuidae
INSE	*Ectoedemia vannifera* (Meyrick, 1914) — Nepticulidae

INSE	*Ectomocoris quadrimaculatus* (Serville, 1831) — Reduviidae
VASC	*Edmondia sesamoides* (L.) Hilliard — Asteraceae
INSE	*Edocla quadrimaculata* Reuter, 1881 — Reduviidae
INSE	*Edocla vittipennis* Stål, 1859 — Reduviidae
VASC	*Ehretia rigida* (Thunb.) Druce — Boraginaceae
VASC	*Ehrharta barbinodis* Nees ex Trin. — Poaceae
VASC	*Ehrharta calycina* Sm. — Poaceae
VASC	*Ehrharta capensis* Thunb. — Poaceae
VASC	*Ehrharta delicatula* (Nees) Stapf — Poaceae
VASC	*Ehrharta erecta* Lam. — Poaceae
VASC	*Ehrharta longiflora* Sm. — Poaceae
VASC	*Ehrharta pusilla* Nees ex Trin. — Poaceae
VASC	*Ehrharta rehmannii* Stapf — Poaceae
VASC	*Ehrharta triandra* Nees ex Trin. — Poaceae
VASC	*Ehrharta villosa* Schult.f. — Poaceae
AVES	*Elanus caeruleus* (Desfontaines, 1789) — Accipitridae
INSE	*Elasmolomus transversus* (Signoret, 1860) — Rhyparochromidae
INSE	*Elattoneura cellularis* (Grünberg, 1902) — Protoneuridae
INSE	*Elattoneura frenulata* (Selys, 1860) — Protoneuridae
INSE	*Elattoneura glauca* (Selys, 1860) — Protoneuridae
VASC	*Elegia cuspidata* Mast. — Restionaceae
VASC	*Elegia filacea* Mast. — Restionaceae
VASC	*Elegia recta* (Mast.) Moline & H.P.Linder — Restionaceae
VASC	*Elegia stipularis* Mast. — Restionaceae
VASC	*Elegia vaginulata* Mast. — Restionaceae
VASC	*Elegia verreauxii* Mast. — Restionaceae
VASC	*Elephantorrhiza elephantina* (Burch.) Skeels — Fabaceae
VASC	*Elephantorrhiza schinziana* Dinter — Fabaceae
MAM	*Elephantulus intufi* (A.Smith, 1836) — Macroscelididae
VASC	*Eleusine indica* (L.) Gaertn. — Poaceae
VASC	*Elionurus tripsacoides* Willd. — Poaceae
AVES	*Emberiza capensis* Linnaeus, 1766 — Emberizidae
AVES	*Emberiza flaviventris* Stephens, 1815 — Emberizidae
AVES	*Emberiza impetuani* Smith, 1836 — Emberizidae
VASC	*Emex australis* Steinh. — Polygonaceae
VASC	*Emilia ambifaria* (S.Moore) C.Jeffrey — Asteraceae
VASC	*Emilia marlothiana* (O.Hoffm.) C.Jeffrey — Asteraceae
INSE	*Encylocotis nasutus* (Stål, 1856) — Enicocephalidae
VASC	*Enneapogon cenchroides* (Roem. & Schult.) C.E.Hubb. — Poaceae
VASC	*Enneapogon desvauxii* P.Beauv. — Poaceae
VASC	*Enneapogon scaber* Lehm. — Poaceae
VASC	*Enneapogon scoparius* Stapf — Poaceae
VASC	*Entada arenaria* Schinz — Aizoaceae
VASC	*Entoplocamia aristulata* (Hack. & Rendle) Stapf — Poaceae
INSE	*Epicephala pyrrhogastra* Meyrick, 1908 — Gracillariidae
INSE	*Epicrosis nigrinella* (Balinsky, 1994) — Pyralidae
INSE	*Epizophorodes capicola* Balinsky, 1994 — Pyralidae
VASC	*Eragrostis annulata* Rendle ex Scott-Elliott — Poaceae
VASC	*Eragrostis aspera* (Jacq.) Nees — Poaceae
VASC	*Eragrostis bicolor* Nees — Poaceae
VASC	*Eragrostis biflora* Hack. ex Schinz — Poaceae
VASC	*Eragrostis cilianensis* (All.) Vignolo ex Janch — Poaceae
VASC	*Eragrostis cimicina* Launert — Poaceae
VASC	*Eragrostis curvula* (Schrad.) Nees — Poaceae
VASC	*Eragrostis cylindriflora* Hochst. — Poaceae
VASC	*Eragrostis dinteri* Stapf — Poaceae
VASC	*Eragrostis echinochloidea* Stapf — Poaceae
VASC	*Eragrostis jeffreysii* Hack. — Poaceae
VASC	*Eragrostis leersiiformis* Launert — Poaceae
VASC	*Eragrostis lehmanniana* Nees — Poaceae
VASC	*Eragrostis macrochlamys* Pilg. var. *macrochlamys* — Poaceae
VASC	*Eragrostis mexicana* subsp. *virescens* (J.Presl. & C.Presl.) S.D.Koch & Sánchez Vega — Poaceae
VASC	*Eragrostis nindensis* Ficalho & Hiern — Poaceae
VASC	*Eragrostis omahekensis* De Winter — Poaceae
VASC	*Eragrostis pallens* Hack. — Poaceae
VASC	*Eragrostis pilgeriana* Dinter ex Pilg. — Poaceae
VASC	*Eragrostis porosa* Nees — Poaceae
VASC	*Eragrostis rigidior* Pilg. — Poaceae
VASC	*Eragrostis rotifer* Rendle — Poaceae
VASC	*Eragrostis scopelophila* Pilg. — Poaceae
VASC	*Eragrostis superba* Peyr. — Poaceae
VASC	*Eragrostis trichophora* Coss. & Durieu — Poaceae
VASC	*Eragrostis truncata* Hack. — Poaceae
VASC	*Eragrostis viscosa* (Retz.) Trin. — Poaceae
AVES	*Eremalauda starki* (Shelley, 1902) — Alaudidae
LICH	*Eremastrella crystallifera* (Taylor) Gotth. Schneid. — Psoraceae
AVES	*Eremomela icteropygialis* (Lafresnaye, 1839) — Sylviidae
AVES	*Eremopterix australis* (A.Smith, 1836) — Alaudidae
VASC	*Erepsia anceps* (Haw.) Schwantes — Aizoaceae
VASC	*Erepsia patula* (Haw.) Schwantes — Aizoaceae
VASC	*Erianthemum dregei* (Eckl. & Zeyh.) Tiegh. — Loranthaceae
VASC	*Erica bruniades* L. — Ericaceae
VASC	*Erica capensis* Salter — Ericaceae
VASC	*Erica cerinthoides* L. — Ericaceae
VASC	*Erica clavisepala* Guthrie & Bolus — Ericaceae
VASC	*Erica coarctata* J.C.Wendl. — Ericaceae
VASC	*Erica coccinea* L. subsp. *coccinea* — Ericaceae
VASC	*Erica corifolia* L. — Ericaceae
VASC	*Erica exleeana* E.G.H.Oliv. — Ericaceae
VASC	*Erica ferrea* P.J.Bergius — Ericaceae
VASC	*Erica glabella* Thunb. subsp. *glabella* — Ericaceae
VASC	*Erica gnaphaloides* L. — Ericaceae
VASC	*Erica imbricata* L. — Ericaceae
VASC	*Erica inaequalis* (Klotzsch) E.G.H.Oliv. — Ericaceae
VASC	*Erica labialis* Salisb. — Ericaceae
VASC	*Erica lasciva* Salisb. — Ericaceae
VASC	*Erica malmesburiensis* E.G.H.Oliv. — Ericaceae
VASC	*Erica mammosa* L. — Ericaceae
VASC	*Erica muscosa* (Aiton) E.G.H.Oliv. — Ericaceae
VASC	*Erica obliqua* Thunb. — Ericaceae
VASC	*Erica plukenetii* L. — Ericaceae
VASC	*Erica plumosa* Thunb. — Ericaceae
VASC	*Erica pulchella* Houtt. — Ericaceae
VASC	*Erica similis* (N.E.Br.) E.G.H.Oliv. — Ericaceae
VASC	*Erica subcapitata* (N.E.Br.) E.G.H.Oliv. — Ericaceae
VASC	*Erica viscaria* L. subsp. *viscaria* — Ericaceae
VASC	*Eriocaulon abyssinicum* Hochst. — Eriocaulaceae
VASC	*Eriocephalus africanus* L. — Asteraceae
VASC	*Eriocephalus africanus* var. *paniculatus* (Cass.) M.A.N.Müller — Asteraceae
VASC	*Eriocephalus luederitzianus* O.Hoffm. — Asteraceae
VASC	*Eriocephalus microphyllus* var. *pubescens* (DC.) M.A.N.Müller — Asteraceae
VASC	*Eriocephalus namaquensis* M.A.N.Müller — Asteraceae
VASC	*Eriocephalus pedicellaris* DC. — Asteraceae
VASC	*Eriocephalus racemosus* L. — Asteraceae
VASC	*Eriocephalus racemosus* L. — Asteraceae
VASC	*Eriospermum alcicorne* Baker — Ruscaceae
VASC	*Eriospermum bakerianum* Schinz subsp. *bakerianum* — Ruscaceae
VASC	*Eriospermum capense* (L.) Thunb. — Ruscaceae
VASC	*Eriospermum flagelliforme* (Baker) J.C.Manning — Ruscaceae
VASC	*Eriospermum nanum* Marloth — Ruscaceae
VASC	*Eriospermum paradoxum* (Jaqc.) Ker Gawl. — Ruscaceae
VASC	*Eriospermum rautanenii* Schinz — Ruscaceae
VASC	*Erodium cicutarium* (L.) L`Her. — Geraniaceae
VASC	*Erucastrum arabicum* Fisch. & C.A.Mey. — Brassicaceae
AVES	*Estrilda astrild* (Linnaeus, 1758) — Estrildidae
INSE	*Eublemma anachoresis* (Wallengren, 1863) — Noctuidae
VASC	*Euclea pseudebenus* E. Meyer ex A. DC. — Ebenaceae
VASC	*Euclea racemosa* Murray — Ebenaceae
VASC	*Euclea tomentosa* E.Mey. ex A.DC. — Ebenaceae
VASC	*Euclea undulata* Thunb. — Ebenaceae
VASC	*Euphorbia arceuthobioides* Boiss. — Euphorbiaceae
VASC	*Euphorbia austro-occidentalis* Thell. — Euphorbiaceae
VASC	*Euphorbia burmannii* E.Mey. ex Boiss. — Euphorbiaceae
VASC	*Euphorbia caput-medusae* L. — Euphorbiaceae
VASC	*Euphorbia celata* R.A.Dyer — Euphorbiaceae
VASC	*Euphorbia chersina* N.E.Br. — Euphorbiaceae
VASC	*Euphorbia crotonoides* Boiss. subsp. *crotonoides* — Euphorbiaceae
VASC	*Euphorbia decussata* E.Mey. ex Boiss. — Euphorbiaceae
VASC	*Euphorbia dregeana* E.Mey. ex Boiss. — Euphorbiaceae
VASC	*Euphorbia ephedroides* E.Mey. ex Boiss. — Euphorbiaceae
VASC	*Euphorbia genistoides* P.J.Bergius — Euphorbiaceae
VASC	*Euphorbia glanduligera* Pax — Euphorbiaceae
VASC	*Euphorbia gregaria* Marloth — Euphorbiaceae

VASC	*Euphorbia gummifera* Boiss. — Euphorbiaceae
VASC	*Euphorbia hamata* (Haw.) Sweet — Euphorbiaceae
VASC	*Euphorbia inaequilatera* Sond. — Euphorbiaceae
VASC	*Euphorbia inaequilatera* Sond. var. *inaequilatera* — Euphorbiaceae
VASC	*Euphorbia juglans* Compton — Euphorbiaceae
VASC	*Euphorbia lignosa* Marloth — Euphorbiaceae
VASC	*Euphorbia mauritanica* L. — Euphorbiaceae
VASC	*Euphorbia multiceps* A.Berger — Euphorbiaceae
VASC	*Euphorbia muricata* Thunb. — Euphorbiaceae
VASC	*Euphorbia neopolycnemoides* Pax & K.Hoffm. — Euphorbiaceae
VASC	*Euphorbia pentops* A.C.White et al. — Euphorbiaceae
VASC	*Euphorbia peplus* L. — Euphorbiaceae
VASC	*Euphorbia phylloclada* Boiss. — Euphorbiaceae
VASC	*Euphorbia silenifolia* (Haw.) Sweet — Euphorbiaceae
VASC	*Euphorbia tuberculata* Jacq. — Euphorbiaceae
VASC	*Euphorbia tuberosa* L. — Euphorbiaceae
INSE	*Eupododus orbicularis* (Burmeister, 1835) — Pentatomidae
AVES	*Eupodotis rueppellii* (Wahlberg, 1856) — Otididae
AVES	*Eupodotis vigorsii* (A.Smith, 1831) — Otididae
INSE	*Eurema brigitta brigitta* (Stoll, 1780) — Pieridae
AVES	*Eurocephalus anguitimens* A.Smith, 1836 — Laniidae
VASC	*Euryops dregeanus* Sch.Bip. — Asteraceae
VASC	*Euryops multifidus* (Thunb.) DC. — Asteraceae
VASC	*Euryops namibensis* (Merxm.) B.Nord. — Asteraceae
VASC	*Euryops tenuissimus* (L.) DC — Asteraceae
INSE	*Eurystylus bellevoyei* (Reuter, 1879) — Miridae
VASC	*Eustegia minuta* (L.f.) Schult. — Apocynaceae
INSE	*Euthetus humilis* Horváth, 1907 — Alydidae
INSE	*Euthetus leucostictus* Stål, 1855 — Alydidae
INSE	*Euthetus pallescens* Distant, 1902 — Alydidae
VASC	*Evolvulus alsinoides* (L.) L. — Convolvulaceae
VASC	*Exacum oldenlandioides* (S.Moore) Klack. — Gentianaceae
INSE	*Exoprosopa* Macquart, 1840 — Bombyliidae
VASC	*Fadogia thamnus* K.Schum. — Rubiaceae
VASC	*Fagonia isotricha* Murb. — Zygophyllaceae
VASC	*Fagonia isotricha* Murb. var. *isotricha* — Zygophyllaceae
AVES	*Falco biarmicus* Temminck, 1825 — Falconidae
AVES	*Falco chicquera* Daudin, 1800 — Falconidae
AVES	*Falco naumanni* Fleischer, 1818 — Falconidae
AVES	*Falco pelegrinoides* Temminck, 1829 — Falconidae
AVES	*Falco tinnunculus* Linnaeus, 1758 — Falconidae
VASC	*Felicia alba* Grau — Asteraceae
VASC	*Felicia australis* (Alston) E.Phillips — Asteraceae
VASC	*Felicia bergeriana* (Spreng.) O.Hoffm. — Asteraceae
VASC	*Felicia brevifolia* (DC.) Grau — Asteraceae
VASC	*Felicia clavipilosa* Grau — Asteraceae
VASC	*Felicia filifolia* (Vent.) Burtt Davy — Asteraceae
VASC	*Felicia merxmuelleri* Grau — Asteraceae
VASC	*Felicia microsperma* DC. — Asteraceae
VASC	*Felicia namaquana* (Harv.) Merxm. — Asteraceae
VASC	*Felicia smaragdina* (S.Moore) Merxm. — Asteraceae
VASC	*Felicia tenella* (L.) Nees — Asteraceae
INSE	*Felinopsis africana* (Schaus, 1893) — Noctuidae
VASC	*Ferraria divaricata* Sweet — Iridaceae
VASC	*Ferraria ferrariola* (Jaqc.) Willd. — Iridaceae
VASC	*Ferraria glutinosa* (Baker) Rendle — Iridaceae
VASC	*Ferraria uncinata* Sweet — Iridaceae
VASC	*Ferraria uncinata* subsp. *macrochlamys* (Baker) M.P.de Vos — Iridaceae
VASC	*Ferraria variabilis* Goldblatt & J.C.Manning — Iridaceae
VASC	*Ficinia anceps* Nees — Cyperaceae
VASC	*Ficinia bulbosa* (L.) Nees — Cyperaceae
VASC	*Ficinia deusta* (P.J.Bergius) Levyns — Cyperaceae
VASC	*Ficinia indica* (Lam.) Pfeiff — Cyperaceae
VASC	*Ficinia lateralis* (Vahl) Kunth — Cyperaceae
VASC	*Ficinia oligantha* (Steud.) J.Raynal — Cyperaceae
VASC	*Ficinia paradoxa* (Schrad.) Nees — Cyperaceae
VASC	*Ficinia rigida* Levyns — Cyperaceae
VASC	*Ficinia secunda* (Vahl) Kunth — Cyperaceae
VASC	*Ficinia tristachya* (Rottb.) Nees — Cyperaceae
VASC	*Ficinia zeyheri* Boeck. — Cyperaceae
VASC	*Ficus ilicina* (Sond.) Miq. — Moraceae
VASC	*Fingerhuthia africana* Lehm. — Poaceae
LICH	*Flavoparmelia soredians* (Nyl.) Hale — Parmeliaceae
LICH	*Flavopunctelia flaventior* (Stirt.) Hale — Parmeliaceae
LICH	*Flavopunctelia soredica* (Nyl.) Hale — Parmeliaceae
VASC	*Fockea angustifolia* K.Schum. — Apocynaceae
VASC	*Fockea comaru* (E.Mey.) N.E.Br. — Apocynaceae
VASC	*Fockea multiflora* K.Schum. — Apocynaceae
VASC	*Forsskaolea candida* L.f. — Urticaceae
VASC	*Forsskaolea viridis* Ehrenb. ex Webb — Urticaceae
VASC	*Foveolina dichotoma* (DC.) Källersjö — Asteraceae
AVES	*Francolinus adspersus* Waterhouse, 1838 — Phasianidae
AVES	*Francolinus swainsonii* (A.Smith, 1836) — Phasianidae
INSE	*Fulleritermes* Coaton, 1963 — Termitidae
VASC	*Fumaria muralis* Sond. ex W.D.J.Koch subsp. *muralis* — Fumariaceae
INSE	*Galeatus scrophicus* Saunders, 1876 — Tingidae
VASC	*Galenia africana* L. — Aizoaceae
VASC	*Galenia crystallina* (Eckl. & Zeyh.) Fenzl — Aizoaceae
VASC	*Galenia dregeana* Fenzl ex Sond. — Aizoaceae
VASC	*Galenia ecklonis* Walpers — Aizoaceae
VASC	*Galenia fruticosa* (L.f.) Sond. — Aizoaceae
VASC	*Galenia meziana* K.Müll. — Aizoaceae
VASC	*Galenia papulosa* (Eckl. & Zeyh.) Sond. — Aizoaceae
VASC	*Galenia sarcophylla* Fenzl — Aizoaceae
MAM	*Galerella sanguinea* (Rüppell, 1835) — Herpestidae
AVES	*Galerida magnirostris* (Stephens, 1826) — Alaudidae
VASC	*Galium tomentosum* Thunb. — Rubiaceae
INSE	*Galtara nepheloptera* (Hampson, 1910) — Arctiidae
VASC	*Gardenia brachythamnus* (K.Schum.) Launert — Rubiaceae
VASC	*Gardenia ternifolia* Schumach. & Thonn. — Rubiaceae
VASC	*Gasteria pillansii* Kensit — Asphodelaceae
VASC	*Gazania ciliaris* DC. — Asteraceae
VASC	*Gazania heterochaeta* DC. — Asteraceae
VASC	*Gazania krebsiana* Less. — Asteraceae
VASC	*Gazania krebsiana* Less. subsp. *krebsiana* — Asteraceae
VASC	*Gazania lichtensteinii* Less. — Asteraceae
VASC	*Gazania othonnites* (Thunb.) Less — Asteraceae
VASC	*Gazania tenuifolia* Less. — Asteraceae
VASC	*Geigeria acaulis* (Sch.Bip.) Benth & Hook.f. ex Oliv. & Hiern — Asteraceae
VASC	*Geigeria alata* (Hochst. & Steud) Benth & Hook.f. ex Oliv. & Hiern — Asteraceae
VASC	*Geigeria ornativa* O.Hoffm. — Asteraceae
VASC	*Geigeria pectidea* (DC.) Harv. — Asteraceae
VASC	*Geigeria pilifera* Hutch. — Asteraceae
VASC	*Geissorhiza aspera* Goldblatt — Iridaceae
VASC	*Geissorhiza eurystigma* L.Bolus — Iridaceae
VASC	*Geissorhiza furva* Ker Gawl. ex Baker — Iridaceae
VASC	*Geissorhiza imbricata* (D.Delaroche) Ker Gawl. — Iridaceae
VASC	*Geissorhiza juncea* (Link) A.Dietr. — Iridaceae
VASC	*Geissorhiza purpureolutea* Baker — Iridaceae
VASC	*Geissorhiza tenella* Goldblatt — Iridaceae
VASC	*Geissorhiza tulbaghensis* F.Bolus — Iridaceae
REPT	*Geochelone pardalis* (Bell, 1828) — Testudinidae
INSE	*Geocoris phaeopterus* (Germar, 1838) — Geocoridae
INSE	*Geocoris stellatus* (Montandon, 1907) — Geocoridae
VASC	*Gerbera crocea* (L.) Kuntze — Asteraceae
MAM	*Gerbilliscus leucogaster* (Peters, 1852) — Muridae
MAM	*Gerbillurus paeba* (A.Smith, 1836) — Muridae
MAM	*Gerbillurus vallinus* (Thomas, 1918) — Muridae
VASC	*Gethyllis afra* L. — Amaryllidaceae
VASC	*Gethyllis britteniana* Baker — Amaryllidaceae
VASC	*Gethyllis namaquensis* (Schönland) Oberm. — Amaryllidaceae
VASC	*Gethyllis spiralis* (Thunb.) Thunb. — Amaryllidaceae
VASC	*Gethyllis villosa* (Thunb.) Thunb. — Amaryllidaceae
VASC	*Gisekia africana* (Lour.) Kuntze — Gisekiaceae
VASC	*Gisekia pharnacioides* L. — Gisekiaceae
VASC	*Gladiolus alatus* L. — Iridaceae
VASC	*Gladiolus orchidiflorus* Andrews — Iridaceae
VASC	*Gladiolus saccatus* (Klatt) Goldblatt & M.P.de Vos — Iridaceae
VASC	*Gladiolus trichonemifolius* Ker Gawl. — Iridaceae
VASC	*Gladiolus venustus* G.J.Lewis — Iridaceae
AVES	*Glaucidium perlatum* (M.H.K.Lichtenstein, 1842) — Strigidae
LICH	*Gloeoheppia turgida* (Ach.) Gyeln. — Gloeoheppiaceae
VASC	*Gloriosa superba* L. — Colchicaceae
VASC	*Gnaphalium pauciflorum* DC. — Asteraceae

VASC	*Gnidia juniperifolia* Lam. — Thymelaeaceae
VASC	*Gnidia oppositifolia* L. — Thymelaeaceae
VASC	*Gnidia pedunculata* Beyers — Thymelaeaceae
VASC	*Gnidia penicillata* Licht. ex Meisn. — Thymelaeaceae
VASC	*Gnidia pinifolia* L. — Thymelaeaceae
VASC	*Gnidia polycephala* (C.A.Mey.) Gilg — Thymelaeaceae
VASC	*Gnidia scabra* Thunb. — Thymelaeaceae
VASC	*Gnidia spicata* (L.f.) Gilg — Thymelaeaceae
VASC	*Gnidia tomentosa* L. — Thymelaeaceae
INSE	*Goellneriana deckerti* Van Doesburg, 2004 — Reduviidae
INSE	*Gomphidia quarrei* (Schouteden, 1934) — Gomphidae
VASC	*Gomphocarpus fruticosus* (L.) Aiton f. subsp. *fruticosus* — Apocynaceae
VASC	*Gomphocarpus tomentosus* Burch. — Apocynaceae
VASC	*Gomphrena celosioides* Mart. — Amaranthaceae
INSE	*Gonometa postica* Walker, 1855 — Lasiocampidae
VASC	*Gorteria diffusa* Thunb. — Asteraceae
VASC	*Gorteria diffusa* Thunb. subsp. *diffusa* — Asteraceae
VASC	*Gorteria personata* L. — Asteraceae
VASC	*Grewia avellana* Hiern — Tiliaceae
VASC	*Grewia bicolor* Juss. — Tiliaceae
VASC	*Grewia falcistipula* K.Schum. — Tiliaceae
VASC	*Grewia flava* DC. — Tiliaceae
VASC	*Grewia flavescens* Juss. — Tiliaceae
VASC	*Grewia olukondae* Schinz — Tiliaceae
VASC	*Grewia retinervis* Burret — Tiliaceae
VASC	*Grewia schinzii* K.Schum. — Tiliaceae
VASC	*Grewia subspathulata* N.E.Br. — Tiliaceae
VASC	*Grewia tenax* (Forsk.) Fiori — Tiliaceae
VASC	*Grewia villosa* Willd. — Tiliaceae
VASC	*Grielum humifusum* Thunb. — Neuradaceae
VASC	*Guibourtia coleosperma* (Benth.) J.Leonard — Fabaceae
VASC	*Guilleminea densa* (Willd. ex Roem. & Schult.) Moq. — Amaranthaceae
VASC	*Gymnodiscus capillaris* (L.f.) DC. — Asteraceae
VASC	*Gymnodiscus linearifolia* DC. — Asteraceae
VASC	*Gymnosporia senegalensis* (Lam.) Loes. — Celastraceae
INSE	*Gynacantha manderica* Grünberg, 1902 — Aeshnidae
INSE	*Gynacantha villosa* Grünberg, 1902 — Aeshnidae
INSE	*Haedus agalisticus* Göllner-Scheiding — Tingidae
INSE	*Haedus foetidus* Göllner-Scheiding, 2003 — Tingidae
VASC	*Haemanthus coccineus* L. — Amaryllidaceae
INSE	*Haemobaphus concinnus* (Dallas, 1852) — Lygaeidae
AVES	*Halcyon chelicuti* (Stanley, 1814) — Alcedinidae
VASC	*Hallianthus planus* (L.Bolus) H.E.K.Hartmann — Aizoaceae
INSE	*Hamanumida daedalus* (Fabricius, 1775) — Nymphalidae
VASC	*Harpagophytum procumbens* (Burch.) DC. ex Meisn. — Pedaliaceae
VASC	*Harpagophytum zeyheri* Decne. — Pedaliaceae
VASC	*Harveya bolusii* Kuntze — Orobanchaceae
VASC	*Haworthia arachnoidea* (L.) Duval — Asphodelaceae
VASC	*Haworthia nortieri* G.G.Sm. — Asphodelaceae
VASC	*Haworthia venosa* subsp. *tessellata* (Haw.) M.B.Bayer — Asphodelaceae
VASC	*Hebenstretia fastigiosa* Jaroscz — Scrophulariaceae
VASC	*Hebenstretia parviflora* E.Mey. — Scrophulariaceae
VASC	*Hebenstretia robusta* E.Mey. — Scrophulariaceae
INSE	*Heegeria tangirica* (Saunders, 1877) — Alydidae
VASC	*Helichrysum alsinoides* DC. — Asteraceae
VASC	*Helichrysum candolleanum* H.Buek — Asteraceae
VASC	*Helichrysum cochleariforme* DC. — Asteraceae
VASC	*Helichrysum cylindriflorum* (L.) Hilliard & B.L.Burtt — Asteraceae
VASC	*Helichrysum dregeanum* Sond. & Harv. — Asteraceae
VASC	*Helichrysum gariepinum* DC. — Asteraceae
VASC	*Helichrysum hebelepis* DC. — Asteraceae
VASC	*Helichrysum herniarioides* DC. — Asteraceae
VASC	*Helichrysum indicum* (L.) Grierson — Asteraceae
VASC	*Helichrysum interjacens* Hilliard — Asteraceae
VASC	*Helichrysum leontonyx* DC. — Asteraceae
VASC	*Helichrysum marifolium* DC. — Asteraceae
VASC	*Helichrysum moeserianum* Thell. — Asteraceae
VASC	*Helichrysum obtusum* (S.Moore) Moeser — Asteraceae
VASC	*Helichrysum patulum* (L.) D.Don — Asteraceae
VASC	*Helichrysum pulchellum* DC. — Asteraceae
VASC	*Helichrysum roseo-niveum* Marloth & O.Hoffm. — Asteraceae
VASC	*Helichrysum rutilans* (L.) D.Don — Asteraceae
VASC	*Helichrysum tomentosulum* (Klatt) Merxm. — Asteraceae
VASC	*Helichrysum tomentosulum* (Klatt) Merxm. subsp. *tomentosulum* — Asteraceae
VASC	*Helichrysum zeyheri* Less. — Asteraceae
VASC	*Helinus integrifolius* (Lam.) Kuntze — Rhamnaceae
VASC	*Helinus spartioides* (Engl.) Schinz ex Engl. — Rhamnaceae
VASC	*Heliophila arenaria* Sond. — Brassicaceae
VASC	*Heliophila coronopifolia* L. — Brassicaceae
VASC	*Heliophila digitata* L.f. — Brassicaceae
VASC	*Heliophila gariepina* Schltr. — Brassicaceae
VASC	*Heliophila lactea* Schltr. — Brassicaceae
VASC	*Heliophila leptophylla* Schltr. — Brassicaceae
VASC	*Heliophila pusilla* L.f. — Brassicaceae
VASC	*Heliophila pusilla* L.f. var. *pusilla* — Brassicaceae
VASC	*Heliophila trifurca* Burch. ex DC. — Brassicaceae
VASC	*Heliophila variabilis* Burch. ex DC. — Brassicaceae
VASC	*Heliotropium ciliatum* Kaplan — Boraginaceae
VASC	*Heliotropium marifolium* Koen. ex. Retz. — Boraginaceae
VASC	*Heliotropium ovalifolium* Forssk. — Boraginaceae
VASC	*Heliotropium steudneri* Vatke — Boraginaceae
VASC	*Heliotropium strigosum* Willd. — Boraginaceae
VASC	*Heliotropium tubulosum* E.Mey. ex A.DC. — Boraginaceae
VASC	*Heliotropium zeylanicum* (Burm.f.) Lam. — Boraginaceae
VASC	*Hemimeris racemosa* (Houtt.) Merr. — Scrophulariaceae
VASC	*Hemimeris sabulosa* L.f. — Scrophulariaceae
INSE	*Hemistigma albipunctum* (Rambur, 1842) — Libellulidae
VASC	*Hemizygia bracteosa* (Benth.) Briq. — Lamiaceae
VASC	*Hemizygia petrensis* (Hiern) M.Ashby — Lamiaceae
INSE	*Heniocha dyops* (Maassen, 1872) — Saturniidae
LICH	*Heppia adglutinata* (Kremp.) A. Massal. — Heppiaceae
LICH	*Heppia arenacea* M. Schultz — Heppiaceae
LICH	*Heppia despreauxii* (Mont.) Tuck. — Heppiaceae
VASC	*Hereroa odorata* (L.Bolus) L.Bolus — Aizoaceae
VASC	*Hermannia abrotanoides* Schrad. — Sterculiaceae
VASC	*Hermannia affinis* K.Schum — Sterculiaceae
VASC	*Hermannia amoena* Dinter ex Friedr.- Holzh. — Sterculiaceae
VASC	*Hermannia bicolor* Engl. & Dinter — Sterculiaceae
VASC	*Hermannia burchellii* (Sweet) I.Verd — Sterculiaceae
VASC	*Hermannia cuneifolia* Jacq. — Sterculiaceae
VASC	*Hermannia cuneifolia* Jacq. var. *cuneifolia* — Sterculiaceae
VASC	*Hermannia cuneifolia* var. *glabrescens* (Harv.) I.Verd. — Sterculiaceae
VASC	*Hermannia damarana* Baker f. — Sterculiaceae
VASC	*Hermannia decumbens* Willd ex Spreng. — Sterculiaceae
VASC	*Hermannia diversistipula* Presl ex Harv. var. *diversistipula* — Sterculiaceae
VASC	*Hermannia eenii* Baker — Sterculiaceae
VASC	*Hermannia fruticulosa* K.Schum. — Sterculiaceae
VASC	*Hermannia glanduligera* K.Schum. — Sterculiaceae
VASC	*Hermannia guerkeana* K.Schum. — Sterculiaceae
VASC	*Hermannia modesta* (Ehrenb.) Mast. — Sterculiaceae
VASC	*Hermannia odorata* Aiton — Sterculiaceae
VASC	*Hermannia quartiniana* A.Rich. — Sterculiaceae
VASC	*Hermannia rautanenii* Schinz ex K.Schum. — Sterculiaceae
VASC	*Hermannia scabra* Cav. — Sterculiaceae
VASC	*Hermannia stricta* (E.Mey. ex Turcz.) Harv. — Sterculiaceae
VASC	*Hermannia tomentosa* (Turcz.) Schinz ex Engl. — Sterculiaceae
VASC	*Hermannia trifurca* L. — Sterculiaceae
VASC	*Hermannia viscosa* Hiern — Sterculiaceae
VASC	*Hermas villosa* (L.) Thunb. — Apiaceae
VASC	*Hermbstaedtia angolensis* C.B.Clarke — Amaranthaceae
VASC	*Hermbstaedtia argenteiformis* Schimz — Amaranthaceae
VASC	*Hermbstaedtia fleckii* (Schinz) Baker & C.B.Clarke — Amaranthaceae
VASC	*Hermbstaedtia glauca* (J.C.Wendl.) Rchb. ex Steud. — Amaranthaceae
VASC	*Hermbstaedtia linearis* Schinz — Amaranthaceae
VASC	*Hermbstaedtia odorata* (Burch) T.Cooke — Amaranthaceae
VASC	*Hermbstaedtia schaeferi* (Schinz) Schinz & Dinter — Amaranthaceae
VASC	*Hesperantha pilosa* (L.f.) Ker Gawl. — Iridaceae
VASC	*Hesperantha radiata* (Jacq.) Ker Gawl. — Iridaceae
VASC	*Hessea breviflora* Herb. — Amaryllidaceae

VASC	*Hessea cinnamomea* (L'Hér.) T.Durand & Schinz — Amaryllidaceae
VASC	*Heteranthera callifolia* Rchb. ex Kunth — Pontederiaceae
LICH	*Heteroplacidium acarosporoides* (Zahlbr.) Breuss — Verrucariaceae
VASC	*Heteropogon contortus* (L.) Roem. & Schult. — Poaceae
VASC	*Heteropogon melanocarpus* (Elliot) Benth. — Poaceae
VASC	*Hibiscus caesius* Garcke — Malvaceae
VASC	*Hibiscus calyphyllus* Cav. — Malvaceae
VASC	*Hibiscus elliottiae* Harv. — Malvaceae
VASC	*Hibiscus fleckii* Gürke — Malvaceae
VASC	*Hibiscus marlothianus* K.Schum. — Malvaceae
VASC	*Hibiscus micranthus* L.f. — Malvaceae
VASC	*Hibiscus nigricaulis* Baker f. — Malvaceae
VASC	*Hibiscus palmatus* Forssk. — Malvaceae
VASC	*Hibiscus schinzii* Gürke — Malvaceae
VASC	*Hibiscus sidiformis* Baill. — Malvaceae
VASC	*Hibiscus trionum* L. — Malvaceae
AVES	*Hieraaetus pennatus* (J.F.Gmelin, 1788) — Accipitridae
VASC	*Hirpicium alienatum* (Thunb.) Druce — Asteraceae
VASC	*Hirpicium echinus* Less. — Asteraceae
VASC	*Hirpicium gazanioides* (Harv.) Roessler — Asteraceae
VASC	*Hirpicium gorterioides* (Oliv. & Hiern) Roessler — Asteraceae
VASC	*Hirpicium gorterioides* (Oliv. & Hiern) Roessler subsp. *gorterioides* — Asteraceae
AVES	*Hirundo rustica* Linnaeus, 1758 — Hirundinidae
AVES	*Hirundo semirufa* Sundevall, 1850 — Hirundinidae
INSE	*Hodotermes mossambicus* (Hagen, 1853) — Hodotermitidae
VASC	*Hoffmannseggia burchellii* (DC.) Benth. ex Oliv. — Fabaceae
VASC	*Hoffmannseggia lactea* (Schinz) Schinz — Fabaceae
VASC	*Holcus setiger* Nees — Poaceae
INSE	*Holoterpna errata* Prout, 1922 — Geometridae
VASC	*Holothrix villosa* Lindl. — Orchidaceae
INSE	*Holotrichius lividus* Burmeister, 1835 — Reduviidae
VASC	*Hoodia gordonii* (Masson) Sweet ex Decne. — Apocynaceae
VASC	*Hoodia pedicellata* (Schinz) Plowes — Apocynaceae
INSE	*Hoplitis* Klug, 1807 — Megachilidae
VASC	*Hoplophyllum spinosum* DC. — Asteraceae
VASC	*Hordeum murinum* L. — Poaceae
INSE	*Horridipamera perlonga* (Scudder, 1971) — Rhyparochromidae
INSE	*Horridopamera ferruginosa* (Stål, 1874) — Rhyparochromidae
INSE	*Horvathiolus delicatulus* (Stål, 1855) — Lygaeidae
INSE	*Hyalochilus scudderi* Slater, 1964 — Rhyparochromidae
VASC	*Hyobanche sanguinea* L. — Orobanchaceae
VASC	*Hyparrhenia filipendula* (Hochst.) Stapf — Poaceae
VASC	*Hyparrhenia hirta* (L.) Stapf — Poaceae
LICH	*Hyperphyscia adglutinata* (Flörke) H. Mayrhofer & Poelt — Physciaceae
LICH	*Hyperphyscia granulata* (Poelt) Moberg — Physciaceae
LICH	*Hyperphyscia pruinosa* Moberg — Physciaceae
LICH	*Hyperphyscia syncolla* (Tuck. ex Nyl.) Kalb — Physciaceae
VASC	*Hypertelis bowkeriana* Sond. — Molluginaceae
VASC	*Hyperthelia dissoluta* (Nees ex Steud.) Clayton — Poaceae
VASC	*Hyphaene petersiana* Klotzsch ex Mart. — Arecaceae
LICH	*Hypocenomyce anthracophila* (Nyl.) P. James & Gotth. Schneid. — Ophioparmaceae
VASC	*Hypochaeris glabra* L. — Asteraceae
VASC	*Hypodiscus aristatus* (Thunb.) C.Krauss — Restionaceae
VASC	*Hypodiscus rugosus* Mast. — Restionaceae
VASC	*Hypodiscus willdenowia* (Nees) Mast. — Restionaceae
VASC	*Hypoestes aristata* (Vahl) Sol. ex Roem. & Schult. var. *aristata* — Acanthaceae
VASC	*Hypoestes forskaolii* (Vahl) R.Br. — Acanthaceae
INSE	*Hypolimnas misippus* (Linnaeus, 1764) — Nymphalidae
INSE	*Hypotia bolinalis* (Walker, 1859) — Pyralidae
INSE	*Hypselopus gigas* Burmeister, 1835 — Alydidae
INSE	*Ictinogomphus dundoensis* (Pinhey, 1961) — Gomphidae
INSE	*Ictinogomphus ferox* (Rambur, 1842) — Gomphidae
MAM	*Ictonyx striatus* (Perry, 1810) — Mustelidae
VASC	*Ihlenfeldtia excavata* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC	*Indigastrum argyraeum* (Eckl. & Zeyh.) Schrire — Fabaceae
VASC	*Indigastrum argyroides* (E.Mey.) Schrire — Fabaceae
VASC	*Indigastrum burkeanum* (Benth. ex Harv.) Schrire — Fabaceae
VASC	*Indigastrum parviflorum* (B. Heyne ex Wight & Arn.) Schrire — Fabaceae
VASC	*Indigofera adenocarpa* E.Mey. — Fabaceae
VASC	*Indigofera alternans* DC. — Fabaceae
VASC	*Indigofera amoena* Aiton — Fabaceae
VASC	*Indigofera auricoma* E.Mey. — Fabaceae
VASC	*Indigofera bainesii* Baker — Fabaceae
VASC	*Indigofera baumiana* Harms — Fabaceae
VASC	*Indigofera capillaris* Thunb. — Fabaceae
VASC	*Indigofera charlieriana* Schinz — Fabaceae
VASC	*Indigofera charlieriana* Schinz var. *charlieriana* — Fabaceae
VASC	*Indigofera colutea* (Burm.f.) Merr. — Fabaceae
VASC	*Indigofera cryptantha* Benth. ex Harv. — Fabaceae
VASC	*Indigofera daleoides* Benth. ex Harv. — Fabaceae
VASC	*Indigofera daleoides* Benth. ex Harv. var. *daleoides* — Fabaceae
VASC	*Indigofera filicaulis* Eckl. & Zeyh. — Fabaceae
VASC	*Indigofera filipes* Benth. ex Harv. — Fabaceae
VASC	*Indigofera flabellata* Harv. — Fabaceae
VASC	*Indigofera flavicans* Baker — Fabaceae
VASC	*Indigofera glomerata* E.Mey. — Fabaceae
VASC	*Indigofera heterophylla* Thunb. — Fabaceae
VASC	*Indigofera heterotricha* DC. — Fabaceae
VASC	*Indigofera hochstetteri* Baker — Fabaceae
VASC	*Indigofera hochstetteri* subsp. *streyana* (Merxm.) A.Schreib. — Fabaceae
VASC	*Indigofera holubii* N.E.Br. — Fabaceae
VASC	*Indigofera inhambanensis* Klotzsch — Fabaceae
VASC	*Indigofera ionii* Jarvie & C.H.Stirt. — Fabaceae
VASC	*Indigofera nigromontana* Eckl. & Zeyh. — Fabaceae
VASC	*Indigofera pechuelii* Kuntze — Fabaceae
VASC	*Indigofera procumbens* L. — Fabaceae
VASC	*Indigofera pungens* E.Mey. — Fabaceae
VASC	*Indigofera rautanenii* Baker f. — Fabaceae
VASC	*Indigofera torulosa* E.Mey. var. *torulosa* — Fabaceae
VASC	*Indigofera trita* L.f. — Fabaceae
VASC	*Indigofera trita* subsp. *scabra* (Roth) de Kort & G.Thijsse — Fabaceae
VASC	*Indigofera trita* subsp. *subulata* (Vahl ex Poir.) Ali — Fabaceae
VASC	*Indigofera vicioides* Jaub. & Spach — Fabaceae
VASC	*Indigofera vicioides* Jaub. & Spach var. *vicioides* — Fabaceae
VASC	*Inula graveolens* Oliv. & Hiern. — Asteraceae
VASC	*Inuloides tomentosa* (L.f.) B.Nord. — Asteraceae
INSE	*Iolaus mimosae mimosae* (Trimen, 1874) — Lycaenidae
INSE	*Iolaus subinfuscata subinfuscata* (Grünberg, 1910) — Lycaenidae
VASC	*Ipomoea bolusiana* Schinz — Convolvulaceae
VASC	*Ipomoea bolusiana* Schinz subsp. *bolusiana* — Convolvulaceae
VASC	*Ipomoea chloroneura* Hallier f. — Convolvulaceae
VASC	*Ipomoea coptica* (L.) Roth ex Poem. & Schult. — Convolvulaceae
VASC	*Ipomoea hackeliana* (Schinz) Hallier f. — Convolvulaceae
VASC	*Ipomoea hochstetteri* House — Convolvulaceae
VASC	*Ipomoea leucanthemum* (Klotzsch) Hallier f. — Convolvulaceae
VASC	*Ipomoea magnusiana* Schinz — Convolvulaceae
VASC	*Ipomoea oblongata* E.Mey. & Choisy — Convolvulaceae
VASC	*Ipomoea obscura* (L.) Ker Gawl. — Convolvulaceae
VASC	*Ipomoea obscura* (L.) Ker Gawl. var. *sagittifolia* — Convolvulaceae
VASC	*Ipomoea plebeia* R.Br. — Convolvulaceae
VASC	*Ipomoea plebeia* subsp. *africana* A.Meeuse — Convolvulaceae
VASC	*Ipomoea sinensis* (Desr.) Choisy — Convolvulaceae
VASC	*Ipomoea sinensis* subsp. *blepharosepala* (Hochs. ex A.Rich.) Verdc. ex A.Meeuse — Convolvulaceae
VASC	*Ipomoea verbascoidea* Choisy — Convolvulaceae
VASC	*Ipomoea welwitschii* Vatke ex Hallier f. — Convolvulaceae
INSE	*Ischnura senegalensis* (Rambur, 1842) — Coenagrionidae
VASC	*Ischyrolepis capensis* (L.) H.P.Linder — Restionaceae
VASC	*Ischyrolepis cincinnata* (Mast.) H.P.Linder — Restionaceae
VASC	*Ischyrolepis gaudichaudiana* var. *luxurians* Pillans — Restionaceae
VASC	*Ischyrolepis macer* (Kunth) H.P.Linder — Restionaceae
VASC	*Ischyrolepis monanthos* (Mast.) H.P.Linder — Restionaceae
VASC	*Ischyrolepis paludosa* (Pillans) H.P.Linder — Restionaceae
VASC	*Ischyrolepis sporadica* Esterh. — Restionaceae
VASC	*Ischyrolepis wallichii* (Mast.) H.P.Linder — Restionaceae
VASC	*Isoetes capensis* A.V.Duthie — Isoetaceae
VASC	*Isolepis cernua* (Vahl) Roem. & Schult. — Cyperaceae

VASC *Isolepis hystrix* (Thunb.) Nees — Cyperaceae
VASC *Isolepis incomtula* Nees — Cyperaceae
VASC *Isolepis leucolema* (Nees) C.Archer — Cyperaceae
VASC *Isolepis levynsiana* Muasya & D.A.Simpson — Cyperaceae
VASC *Isolepis ludwigii* (Steud.) Kunth — Cyperaceae
VASC *Isolepis marginata* (Thunb.) A.Dietr. — Cyperaceae
VASC *Isolepis prolifera* (Rottb.) R.Br. — Cyperaceae
VASC *Isolepis rubicunda* (Nees) Kunth — Cyperaceae
INSE *Isturgia deerraria* (Walker, 1861) — Geometridae
VASC *Itasina filifolia* (Thunb.) Raf. — Apiaceae
VASC *Ixia curta* Andrews — Iridaceae
VASC *Ixia lutea* Eckl. — Iridaceae
VASC *Ixia odorata* Ker Gawl. — Iridaceae
VASC *Jacobsenia kolbei* (L.Bolus) L.Bolus & Schwantes — Aizoaceae
VASC *Jacquemontia tamnifolia* (L.) Griseb. — Convolvulaceae
VASC *Jamesbrittenia canescens* var. *seineri* (Pilg.) Hilliard — Scrophulariaceae
VASC *Jamesbrittenia fruticosa* (Benth.) Hilliard — Scrophulariaceae
VASC *Jamesbrittenia hereroensis* (Engl.) Hilliard — Scrophulariaceae
VASC *Jamesbrittenia maxii* (Hiern.) Hilliard — Scrophulariaceae
VASC *Jamesbrittenia pinnatifida* (L.f.) Hilliard — Scrophulariaceae
VASC *Jamesbrittenia racemosa* (Benth.) Hilliard — Scrophulariaceae
VASC *Jatropha curcas* L. — Euphorbiaceae
VASC *Jatropha erythropoda* Pax & K.Hoffm. — Euphorbiaceae
VASC *Jatropha orangeana* Dinter ex P.G.Mey. — Euphorbiaceae
VASC *Jordaaniella cuprea* (L.Bolus) H.E.K.Hartmann — Aizoaceae
VASC *Juncus acutus* L. — Juncaceae
VASC *Juncus acutus* L. subsp. *leopoldii* (Parl.) Snogerup — Juncaceae
VASC *Juncus kraussii* Hochst. — Juncaceae
VASC *Juncus rupestris* Kunth — Juncaceae
INSE *Junonia hierta cebrene* Trimen, 1870 — Nymphalidae
INSE *Junonia oenone oenone* (Linnaeus, 1758) — Nymphalidae
VASC *Justicia betonica* L. — Acanthaceae
VASC *Justicia exigua* S.Moore — Acanthaceae
VASC *Justicia guerkeana* Schinz — Acanthaceae
VASC *Justicia heterocarpa* T.Anderson — Acanthaceae
VASC *Justicia orchioides* L.f. — Acanthaceae
VASC *Justicia protracta* (Nees) T.Anderson — Acanthaceae
VASC *Justicia protracta* subsp. *rhodesiana* (S.Moore) Immelman — Acanthaceae
VASC *Kalanchoe brachyloba* Welw. ex Britten — Crassulaceae
VASC *Kalanchoe lanceolata* (Forssk.) Pers. — Crassulaceae
VASC *Karroochloa schismoides* (Stapf ex Conert) Conert & Türpe — Poaceae
VASC *Kedrostis capensis* (Sond.) A.Meeuse — Cucurbitaceae
VASC *Kedrostis foetidissima* (Jacq.) Cogn. — Cucurbitaceae
VASC *Kedrostis hirtella* (Naudin) Cogn. — Cucurbitaceae
VASC *Kissenia capensis* Endl. — Loasaceae
VASC *Kleinia cephalophora* Compton — Asteraceae
VASC *Kleinia longiflora* DC. — Asteraceae
VASC *Kohautia amboensis* (Schinz) Bremek. — Rubiaceae
VASC *Kohautia aspera* (B.Heyne ex Roth) Bremek. — Rubiaceae
VASC *Kohautia azurea* (Dinter & K.Krause) Bremek. — Rubiaceae
VASC *Kohautia caespitosa* subsp. *brachyloba* (Sond.) D.Mantell — Rubiaceae
VASC *Kohautia cynanchica* DC. — Rubiaceae
VASC *Kohautia subverticillata* (K.Schum.) D.Mantell — Rubiaceae
VASC *Kohautia subverticillata* (K.Schum.) D.Mantell subsp. *subverticillata* — Rubiaceae
VASC *Kohautia virgata* (Willd.) Bremek. — Rubiaceae
VASC *Kyllinga alata* Nees — Cyperaceae
VASC *Kyllinga alba* Nees — Cyperaceae
VASC *Kyllinga welwitschii* Ridl. — Cyperaceae
VASC *Kyphocarpa angustifolia* (Moq.) Lopr. — Amaranthaceae
INSE *Laccocoris limigenus* Stål, 1865 — Naucoridae
VASC *Lachenalia carnosa* Baker — Hyacinthaceae
VASC *Lachenalia concordiana* Schltr. ex W.F.Barker — Hyacinthaceae
VASC *Lachenalia contaminata* Aiton — Hyacinthaceae
VASC *Lachenalia framesii* W.F.Baker — Hyacinthaceae
VASC *Lachenalia mutabilis* Sweet — Hyacinthaceae
VASC *Lachenalia orchioides* (L.) Aiton var. *orchioides* — Hyacinthaceae
VASC *Lachenalia patula* Jacq. — Hyacinthaceae
VASC *Lachenalia polyphylla* Baker — Hyacinthaceae
VASC *Lachenalia pustulata* Jacq. — Hyacinthaceae
VASC *Lachenalia trichophylla* Baker — Hyacinthaceae
VASC *Lachenalia unifolia* Jacq. — Hyacinthaceae
VASC *Lachenalia violacea* Jacq. — Hyacinthaceae
VASC *Lachenalia zeyher*i Baker — Hyacinthaceae
VASC *Lachnaea capitata* (L.) Crantz — Thymelaeaceae
VASC *Lachnaea densiflora* Meisn. — Thymelaeaceae
VASC *Lachnaea grandiflora* (L.f.) Baill. — Thymelaeaceae
VASC *Lachnaea uniflora* (L.) Crantz — Thymelaeaceae
INSE *Lachnesthus singalensis* (Dohrn, 1860) — Rhyparochromidae
VASC *Lachnospermum fasciculatum* (Thunb.) Baillon — Asteraceae
VASC *Lachnospermum imbricatum* (P.J.Bergius) Hillard — Asteraceae
VASC *Laggera crispata* (Vahl) Hepper & J.R.I.Wood — Asteraceae
VASC *Laggera decurrens* (Vahl) Herper & J.R.I.Wood — Asteraceae
INSE *Lalervis tibialis* (Stål, 1854) — Cydnidae
INSE *Lamottellus hirsutus* Villiers, 1948 — Reduviidae
INSE *Lampides boeticus* (Linnaeus, 1767) — Lycaenidae
VASC *Lampranthus bicolor* (L.) N.E.Br. — Aizoaceae
VASC *Lampranthus citrinus* (L.Bolus) L.Bolus — Aizoaceae
VASC *Lampranthus densipetalus* (L.Bolus) L.Bolus — Aizoaceae
VASC *Lampranthus emarginatus* (L.) N.E.Br. — Aizoaceae
VASC *Lampranthus falciformis* (Haw.) N.E.Br. — Aizoaceae
VASC *Lampranthus filicaulis* (Haw.) N.E.Br. — Aizoaceae
VASC *Lampranthus godmaniae* (L.Bolus) L.Bolus — Aizoaceae
VASC *Lampranthus hallii* L.Bolus — Aizoaceae
VASC *Lampranthus hoerleinianus* (Dinter) Friedrich — Aizoaceae
VASC *Lampranthus leptaleon* (Haw.) N.E.Br. — Aizoaceae
VASC *Lampranthus otzenianus* (Dinter) Friedrich — Aizoaceae
VASC *Lampranthus peacockiae* (L.Bolus) L.Bolus — Aizoaceae
VASC *Lampranthus reptans* (Aiton) N.E.Br. — Aizoaceae
VASC *Lampranthus scaber* (L.) N.E.Br. — Aizoaceae
VASC *Lampranthus spiniformis* (Haw.) N.E.Br. — Aizoaceae
VASC *Lampranthus tenuifolius* (L.) N.E.Br. — Aizoaceae
VASC *Lampranthus uniflorus* (L.Bolus) L.Bolus — Aizoaceae
VASC *Lampranthus watermeyeri* (L.Bolus) N.E.Br. — Aizoaceae
AVES *Lamprotornis nitens* (Linnaeus, 1766) — Sturnidae
AVES *Laniarius atrococcineus* (Burchell, 1822) — Malaconotidae
AVES *Lanioturdus torquatus* Waterhouse, 1838 — Platysteiridae
AVES *Lanius collaris* Linnaeus, 1766 — Laniidae
AVES *Lanius collurio* Linnaeus, 1758 — Laniidae
AVES *Lanius minor* Gmelin, 1788 — Laniidae
VASC *Lannea gossweileri* Exell & Mendonca subsp. *gossweileri* — Anacardiaceae
VASC *Lannea zastrowiana* Engl. & Brehmer — Anacardiaceae
VASC *Lantana angolensis* Moldenke — Verbenaceae
VASC *Lantana camara* L. — Verbenaceae
VASC *Lantana dinteri* Moldenke — Verbenaceae
VASC *Lapeirousia anceps* (L.f.) Ker Gawl. — Iridaceae
VASC *Lapeirousia arenicola* Schltr. — Iridaceae
VASC *Lapeirousia azurea* (Eckl. ex Baker) Goldblatt — Iridaceae
VASC *Lapeirousia bainesii* Baker — Iridaceae
VASC *Lapeirousia barklyi* Baker — Iridaceae
VASC *Lapeirousia coerulea* Schinz — Iridaceae
VASC *Lapeirousia corymbosa* (L.) Ker Gawl. — Iridaceae
VASC *Lapeirousia divaricata* Baker — Iridaceae
VASC *Lapeirousia dolomitica* Dinter subsp. *dolomitica* — Iridaceae
VASC *Lapeirousia fabricii* (D.Delaroche) Ker Gawl. — Iridaceae
VASC *Lapeirousia pyramidalis* (Lam.) Goldblatt — Iridaceae
VASC *Lapeirousia silenoides* (Jacq.) Ker Gawl. — Iridaceae
VASC *Lapeirousia spinosa* (Goldblatt) Goldblatt & J.C.Manning — Iridaceae
VASC *Lappula capensis* (DC.) Gürke — Boraginaceae
VASC *Larryleachia cactiformis* (Hooker) Plowes — Apocynaceae
INSE *Lasiacantha kamanyabensis* Duarte Rodrigues, 1987 — Tingidae
VASC *Lasiopogon brachypterus* O.Hoffm. ex Zahlbr. — Asteraceae
VASC *Lasiopogon micropoides* DC. — Asteraceae
VASC *Lasiospermum brachyglossum* DC. — Asteraceae
VASC *Launaea intybacea* (Jacq.) P.Beauv. — Asteraceae
VASC *Laurembergia repens* P.J.Bergius — Haloragaceae
VASC *Lebeckia contaminata* (L.) Thunb. — Fabaceae
VASC *Lebeckia halenbergensis* Merxm. & A.Schreib. — Fabaceae
VASC *Lebeckia leipoldtiana* Schltr. ex R.Dahlgren — Fabaceae
VASC *Lebeckia meyeriana* Eckl. & Zeyh. — Fabaceae
VASC *Lebeckia multiflora* E.Mey. — Fabaceae
VASC *Lebeckia plukenetiana* E.Mey. — Fabaceae

VASC	*Lebeckia sericea* Thunb. — Fabaceae
VASC	*Lebeckia spinescens* Harv. — Fabaceae
LICH	*Lecanora chlarotera* Nyl. — Lecanoraceae
LICH	*Lecanora dispersa* (Pers.) Röhl. — Lecanoraceae
LICH	*Lecanora expallens* Ach. — Lecanoraceae
LICH	*Lecanora symmicta* (Ach.) Ach. — Lecanoraceae
LICH	*Lecidea sarcogynoides* Körb. — Lecideaceae
LICH	*Lecidella crystallina* V. Wirth & Vězda — Lecanoraceae
LICH	*Lecidella placodina* (Zahlbr.) Hertel — Lecanoraceae
VASC	*Ledebouria cooperi* (Hook.f.) Jessop — Hyacinthaceae
VASC	*Ledebouria undulata* (Jacq.) Jessop — Hyacinthaceae
VASC	*Leipoldtia schultzei* (Schltr. & Diels) Friedrich — Aizoaceae
VASC	*Lepidium africanum* (Burm.f.) DC. — Brassicaceae
VASC	*Lepidium desertorum* Eckl. & Zeyh. — Brassicaceae
INSE	*Lepidochrysops glauca glauca* (Trimen, 1887) — Lycaenidae
INSE	*Lepidochrysops michellae* Henning & Henning, 1983 — Lycaenidae
INSE	*Lepidochrysops plebeia plebeia* (Butler, 1898) — Lycaenidae
INSE	*Lepidotermes* Sjöstedt, 1924 — Termitidae
INSE	*Lepisiota capensis* (Mayr, 1862), — Formicidae
INSE	*Lepisiota* Santschi, 1926 — Formicidae
INSE	*Leptodemus irroratus* Slater, 1972 — Oxycarenidae
INSE	*Leptomyria lara* (Linnaeus, 1764) — Lycaenidae
INSE	*Leptotes babaulti* (Stempffer, 1935) — Lycaenidae
INSE	*Leptotes pirithous pirithous* (Linnaeus, 1767) — Lycaenidae
INSE	*Leptothorax* Mayr, 1855 — Formicidae
MAM	*Lepus saxatilis* Cuvier, 1823 — Leporidae
VASC	*Lessertia argentea* Harv. — Fabaceae
VASC	*Lessertia benguellensis* Baker f. — Fabaceae
VASC	*Lessertia brachypus* Harv. — Fabaceae
VASC	*Lessertia capensis* (P.J.Bergius) Druce — Fabaceae
VASC	*Lessertia capitata* E.Mey. — Fabaceae
VASC	*Lessertia diffusa* R.Br. — Fabaceae
INSE	*Lestes dissimulans* Fraser, 1955 — Lestidae
INSE	*Lestes pallidus* Rambur, 1842 — Lestidae
INSE	*Lestes pinhey*i Fraser, 1955 — Lestidae
INSE	*Lestes plagiatus* (Burmeister, 1839) — Lestidae
INSE	*Lestes tridens* (MacLachlan, 1895) — Lestidae
INSE	*Lestes virgatus* (Burmeister, 1839) — Lestidae
INSE	*Lestinogomphus angustus* Martin, 1911 — Gomphidae
INSE	*Lestinogomphus silkeae* Kipping, 2010 — Gomphidae
INSE	*Lethaeus tartareus* Stål, 1865 — Rhyparochromidae
INSE	*Lethaeus termitarum* (Breddin, 1913) — Rhyparochromidae
VASC	*Leucadendron cinereum* (Sol. ex Aiton) R.Br. — Proteaceae
VASC	*Leucadendron corymbosum* P.J.Bergius — Proteaceae
VASC	*Leucadendron lanigerum* H.Buek ex Meisn. var. *lanigerum* — Proteaceae
VASC	*Leucadendron laureolum* (Lam.) Fourc. — Proteaceae
VASC	*Leucadendron stellare* (Sims) Sweet — Proteaceae
VASC	*Leucadendron xanthoconus* (Kuntze) K. Schum. — Proteaceae
VASC	*Leucas glabrata* (Vahl) Sm. — Lamiaceae
VASC	*Leucas martinicensis* (Jacq.) R.Br. — Lamiaceae
VASC	*Leucas pechuelii* (Kuntze) Gürke — Lamiaceae
INSE	*Leucochitonea levubu* Wallengren, 1857 — Hesperidae
VASC	*Leucophrys mesocoma* (Nees) Rendle — Poaceae
VASC	*Leucoptera oppositifolia* B.Nord. — Asteraceae
VASC	*Leucoptera subcarnosa* B.Nord. — Asteraceae
VASC	*Leucospermum calligerum* (Salisb. ex Knight) Rourke — Proteaceae
VASC	*Leucospermum conocarpodendron* subsp. *viridum* Rourke — Proteaceae
VASC	*Leucospermum hypophyllocarpodendron* (L.) Druce — Proteaceae
VASC	*Leucospermum hypophyllocarpodendron* subsp. *canaliculatum* (H.Buek ex Meisn.) Rourke — Proteaceae
VASC	*Leucospermum parile* (Salisb. ex Knight) Sweet — Proteaceae
VASC	*Leucospermum praecox* Rourke — Proteaceae
VASC	*Leucosphaera bainesii* (Hook.f.) Gilg — Amaranthaceae
VASC	*Leysera gnaphalodes* (L.) L. — Asteraceae
VASC	*Leysera tenella* DC. — Asteraceae
LICH	*Lichinella myriospora* (Zahlbr.) P.P.Moreno & Egea ex Schultz — Lichinaceae
LICH	*Lichinella stipatula* Nyl. — Lichinaceae
VASC	*Lichtensteinia obscura* (Spreng.) Koso-Pol. — Apiaceae
VASC	*Limeum aethiopicum* Burm. — Molluginaceae
VASC	*Limeum africanum* L. — Molluginaceae
VASC	*Limeum arenicolum* G.Schellenb. — Molluginaceae
VASC	*Limeum argute-carinatum* Wawra ex Wawra & Peyr. — Molluginaceae
VASC	*Limeum dinteri* G.Schellenb. — Molluginaceae
VASC	*Limeum fenestratum* (Fenzl) Heimerl — Molluginaceae
VASC	*Limeum myosotis* H.Walter — Molluginaceae
VASC	*Limeum pterocarpum* (J.Gay) Heimerl — Molluginaceae
VASC	*Limeum pterocarpum* (J.Gay) Heimerl var. *pterocarpum* — Molluginaceae
VASC	*Limeum rhombifolium* G.Schellenb. — Molluginaceae
VASC	*Limeum sulcatum* (Klotzsch) Hutch. — Molluginaceae
VASC	*Limeum sulcatum* (Klotzsch) Hutch. var. *sulcatum* — Molluginaceae
VASC	*Limeum viscosum* (J.Gay) Fenzl — Molluginaceae
VASC	*Limeum viscosum* (J.Gay) Fenzl var. *viscosum* — Molluginaceae
VASC	*Limeum viscosum* subsp. *nummulifolium* (H.Walter) Friedrich — Molluginaceae
INSE	*Limnogonus hypoleucus* (Gerstaecker, 1873) — Gerridae
VASC	*Limonium kraussianum* (Buchinger ex Boiss.) Kuntze — Plumbaginaceae
VASC	*Limosella africana* Glück — Scrophulariaceae
INSE	*Linepithema humile* (Mayr, 1868) — Formicidae
VASC	*Linum africanum* L. — Linaceae
VASC	*Linum thunbergii* Eckl. & Zeyh. — Linaceae
INSE	*Liorhyssus hessei* Göllner-Scheiding, 1976 — Rhopalidae
INSE	*Liorhyssus hyalinus* (Fabricius, 1794) — Rhopalidae
INSE	*Liorhyssus natalensis* (Stål, 1855) — Rhopalidae
INSE	*Liorhyssus slateri* Göllner-Scheiding, 1976 — Rhopalidae
VASC	*Liparia parva* Vogel ex Walp. — Fabaceae
VASC	*Liparia splendens* (Burm.f.) Bos & de Wit — Fabaceae
VASC	*Lithops ruschiorum* (Dinter & Schwantes) N.E.Br. — Aizoaceae
VASC	*Lobelia capillifolia* (C.Presl) A.DC. — Lobeliaceae
VASC	*Lobelia comosa* L. — Lobeliaceae
VASC	*Lobelia coronopifolia* L. — Lobeliaceae
VASC	*Lobelia erinus* L. — Lobeliaceae
VASC	*Lobelia jasionoides* (A.DC.) E.Wimm. — Lobeliaceae
VASC	*Lobelia pinifolia* L. — Lobeliaceae
VASC	*Lobelia setacea* Thunb. — Lobeliaceae
VASC	*Lobostemon argenteus* (P.J.Bergius) H.Buek — Boraginaceae
VASC	*Lobostemon capitatus* (L.) H.Buek — Boraginaceae
VASC	*Lobostemon glaucophyllus* (Jacq.) H.Buek — Boraginaceae
VASC	*Lolium perenne* L. — Poaceae
VASC	*Lonchocarpus nelsii* (Schinz) Heering & Grimme — Fabaceae
VASC	*Lophiocarpus polystachyus* Turcz. — Phytolaccaceae
VASC	*Lophiocarpus tenuissimus* Hook.f. — Phytolaccaceae
INSE	*Lophoraglius notablis* (Distant, 1911) — Rhyparochromidae
AVES	*Lophotis ruficrista* (A. Smith, 1836) — Otididae
VASC	*Lotononis brachyantha* Harms — Fabaceae
VASC	*Lotononis complanata* B.-E.van Wyk — Fabaceae
VASC	*Lotononis falcata* (E.Mey.) Benth. — Fabaceae
VASC	*Lotononis involucrata* (P.J.Bergius) Benth. subsp. *involucrata* — Fabaceae
VASC	*Lotononis leptoloba* Bolus — Fabaceae
VASC	*Lotononis listii* Polhill — Fabaceae
VASC	*Lotononis longiflora* Bolus — Fabaceae
VASC	*Lotononis oligocephala* B.-E. van Wyk — Fabaceae
VASC	*Lotononis pachycarpa* Dinter ex B.-E. van Wyk — Fabaceae
VASC	*Lotononis parviflora* (P.J.Bergius) D.Dietr. — Fabaceae
VASC	*Lotononis platycarpa* (Viv.) Pic.Serm. — Fabaceae
VASC	*Lotononis strigillosa* (Merxm. & A.Schreib.) A.Schreib. — Fabaceae
VASC	*Lotus subbiflorus* Lag. — Fabaceae
MAM	*Loxodonta africana* (Blumenbach, 1797) — Elephantidae
AVES	*Lybius leucocephalus* (De Filippi, 1853) — Ramphastidae
VASC	*Lycium bosciifolium* Schinz — Solanaceae
VASC	*Lycium cinereum* Thunb. — Solanaceae
VASC	*Lycium eenii* S.Moore — Solanaceae
VASC	*Lycium ferocissimum* Miers — Solanaceae
VASC	*Lycium hirsutum* Dunal — Solanaceae
VASC	*Lycium oxycarpum* Dunal — Solanaceae
INSE	*Lygaeodema canescens* (Bergroth, 1914) — Lygaeidae
VASC	*Lyperia tristis* (L.f.) Benth. — Scrophulariaceae
VASC	*Macledium speciosum* (DC.) S.Ortiz — Asteraceae
INSE	*Macroscytus brunneus* (Fabricius, 1803) — Cydnidae

VASC *Macrostylis villosa* (Thunb.) Sond. — Rutaceae
INSE *Macrotermes michaelseni* (Sjöstedt, 1914) — Termitidae
VASC *Maerua juncea* Pax. — Capparaceae
VASC *Maerua juncea* Pax subsp. *juncea* — Capparaceae
VASC *Maerua parvifolia* Pax — Capparaceae
VASC *Maerua schinzii* Pax — Capparaceae
INSE *Mafa lanceolata* Hesse, 1925 — Tingidae
VASC *Malephora purpureo-crocea* (Haw.) Schwantes — Aizoaceae
VASC *Malva parviflora* L. var. *parviflora* — Malvaceae
VASC *Manochlamys albicans* (Aiton) Aellen — Chenopodiaceae
VASC *Manulea androsacea* E.Mey. ex Benth — Scrophulariaceae
VASC *Manulea cheiranthus* (L.) L. — Scrophulariaceae
VASC *Manulea corymbosa* L.f. — Scrophulariaceae
VASC *Manulea decipiens* Hilliard — Scrophulariaceae
VASC *Manulea rubra* (P.J.Bergius) L.f. — Scrophulariaceae
VASC *Marasmodes oligocephala* DC. — Asteraceae
VASC *Mariscus confusus* Vorster nom. prov. — Cyperaceae
VASC *Marsdenia sylvestris* (Retz) P.I.Forest. — Asclepiadaceae
VASC *Marsilea aegyptiaca* Willd. — Marsileaceae
VASC *Marsilea vera* Launert — Marsileaceae
INSE *Masoas limbata* (Distant, 1906) — Heterogastridae
VASC *Massonia depressa* Houtt. — Hyacinthaceae
INSE *Mecidea linearis* Dallas, 1851 — Pentatomidae
INSE *Mecidea pallidissima* Jensen-Haarup, 1922 — Pentatomidae
VASC *Medicago laciniata* (L.) Mill. — Fabaceae
VASC *Medicago polymorpha* L. var. *polymorpha* — Fabaceae
VASC *Medicago polymorpha* var. *brevispina* (Benth.) Heyn — Fabaceae
VASC *Medicago polymorpha* var. *vulgaris* (Benth.) Shinners — Fabaceae
VASC *Megalochlamys marlothii* (Engl.) Lindau — Acanthaceae
VASC *Megaloprotachne albescens* C.E.Hubb. — Poaceae
AVES *Melaenornis infuscatus* (A.Smith, 1839) — Muscicapidae
INSE *Melanotelus villosulus* (Stål, 1855) — Lygaeidae
VASC *Melanthera scandens* (Schumach. & Thonn.) Roberty — Asteraceae
VASC *Melanthera triternata* (Klatt) Wild — Asteraceae
VASC *Melhania acuminata* Mast. — Sterculiaceae
VASC *Melhania damarana* Harv. — Sterculiaceae
VASC *Melhania forbesii* Planch. ex Mast. — Sterculiaceae
VASC *Melhania virescens* (K.Schum.) K.Schum. — Sterculiaceae
VASC *Melianthus elongatus* Wijnands — Melianthaceae
AVES *Melierax canorus* (Rislachi, 1799) — Accipitridae
AVES *Melierax gabar* (Daudin, 1800) — Accipitridae
AVES *Melierax metabates* Heuglin, 1861 — Accipitridae
VASC *Melinis kallimorpha* (Clayton) Zizka — Poaceae
VASC *Melinis longiseta* (A.Rich.) Zizka — Poaceae
VASC *Melinis longiseta* subsp. *bellespicata* (Rendle) Zizka — Poaceae
VASC *Melinis repens* (Willd.) Zizka — Poaceae
VASC *Melinis repens* (Willd.) Zizka subsp. *repens* — Poaceae
VASC *Melinis repens* subsp. *grandiflora* (Hochst.) Zizka — Poaceae
VASC *Melolobium adenodes* Eckl. & Zeyh. — Fabaceae
VASC *Melolobium candicans* (E.Mey.) Eckl. & Zeyh. — Fabaceae
VASC *Melolobium humile* Eckl. & Zeyh. — Fabaceae
VASC *Melolobium microphyllum* (L.f.) Eckl. & Zeyh. — Fabaceae
INSE *Menaccarus ciliosus* Stål, 1865 — Pentatomidae
VASC *Mentha longifolia* subsp. *capensis* (Thunb.) Briq. — Lamiaceae
VASC *Merciera tetraloba* C.N.Cupido — Campanulaceae
AVES *Merops apiaster* Linnaeus, 1758 — Meropidae
AVES *Merops hirundineus* Lichtenstein, 1793 — Meropidae
AVES *Merops persicus* (Pallas, 1773) — Meropidae
VASC *Merremia bipinnatipartita* (Engl.) Hallier f. — Convolvulaceae
VASC *Merremia palmata* Hallier f. — Convolvulaceae
VASC *Merremia pinnata* (Hochst. ex Choisy) Hallier f. — Convolvulaceae
VASC *Merremia verecunda* Rendle — Convolvulaceae
VASC *Merxmuellera cincta* (Nees) Conert — Poaceae
VASC *Merxmuellera decora* (Nees) Conert — Poaceae
VASC *Merxmuellera stricta* (Schrad.) Conert — Poaceae
VASC *Mesembryanthemum barklyi* N.E.Br. — Aizoaceae
VASC *Mesembryanthemum cryptanthum* Hook.f. — Aizoaceae
VASC *Mesembryanthemum fastigiatum* Thunb. — Aizoaceae
VASC *Mesembryanthemum guerichianum* Pax — Aizoaceae
VASC *Mesembryanthemum hypertrophicum* Dinter — Aizoaceae
VASC *Mesembryanthemum longistylum* DC. — Aizoaceae
VASC *Mesembryanthemum nodiflorum* L. — Aizoaceae
VASC *Mesembryanthemum pellitum* Friedrich — Aizoaceae
INSE *Mesocnemis singularis* Karsch, 1891 — Platycnemididae
INSE *Metacanthus concolor* (Buchanan-White, 1878) — Berytidae
INSE *Metacnemis angusta* Selys, 1863 — Platycnemididae
INSE *Metacnemis valida* Hagen in Selys, 1863 — Platycnemididae
VASC *Metalasia capitata* (Lam.) Less. — Asteraceae
VASC *Metalasia compacta* Zeyh. ex Sch.Bip. — Asteraceae
VASC *Metalasia densa* (Lam.) P.O.Karis — Asteraceae
VASC *Metalasia fastigiata* (Thunb.) D.Don — Asteraceae
VASC *Metalasia pulchella* (Cass.) P.O.Karis — Asteraceae
INSE *Metisella malgacha malgacha* (Boisduval, 1833) — Hesperiidae
VASC *Meyerophytum meyeri* (Schwantes) Schwantes — Aizoaceae
MAM *Micaelamys namaquensis* (A.Smith, 1834) — Muridae
VASC *Micranthus junceus* (Baker) N.E.Br. — Iridaceae
VASC *Micranthus tubulosus* (Burm.) N.E.Br. — Iridaceae
INSE *Microcerotermes* Silvestri, 1901 — Termitidae
VASC *Microcharis disjuncta* (J.B.Gillet) Schrire — Fabaceae
VASC *Microchloa caffra* Nees — Poaceae
VASC *Microchloa kunthii* Desv. — Poaceae
VASC *Micrococca mercurialis* (L.) Benth. — Euphorbiaceae
VASC *Microcodon glomeratum* A.DC. — Campanulaceae
VASC *Microdon dubius* (L.) Hilliard — Scrophulariaceae
INSE *Microhodotermes viator* (Latreille, 1804) — Hodotermitidae
VASC *Microloma calycinum* E.Mey. — Apocynaceae
VASC *Microloma incanum* Decne. — Apocynaceae
VASC *Microloma namaquense* Bolus — Apocynaceae
VASC *Microloma sagittatum* (L.) R.Br. — Apocynaceae
INSE *Micronecta scutellaris* Stål, 1858 — Corixidae
AVES *Micronisus gabar* Daudin, 1800 — Accipitridae
INSE *Microtermes* Wasmann, 1902 — Termitidae
INSE *Migdilybs furcifer* Hesse, 1925 — Rhyparochromidae
AVES *Milvus aegyptius* (Gmelin, 1788) — Accipitridae
AVES *Milvus migrans* (Boddaert, 1783) — Accipitridae
VASC *Mimetes cucullatus* (L.) R.Br. — Proteaceae
VASC *Mimetes fimbriifolius* Salisb. ex Knight — Proteaceae
AVES *Mirafra africanoides* A.Smith, 1836 — Alaudidae
AVES *Mirafra apiata* (Vieillot, 1816) — Alaudidae
AVES *Mirafra sabota* A.Smith, 1836 — Alaudidae
VASC *Mitrophyllum clivorum* (N.E.Br.) Schwantes — Aizoaceae
VASC *Mohria caffrorum* (L.) Desv. — Anemiaceae
VASC *Mollugo cerviana* (L.) Ser. ex DC. — Molluginaceae
VASC *Mollugo cerviana* (L.) Ser. ex DC. var. *cerviana* — Molluginaceae
VASC *Mollugo nudicaulis* Lam. — Molluginaceae
VASC *Momordica balsamina* L. — Cucurbitaceae
VASC *Momordica humilis* (Cogn.) C.Jeffrey — Cucurbitaceae
VASC *Momordica welwitschii* Hook.f. — Cucurbitaceae
VASC *Monandrus squarrosus* (L.) Vorster — Cyperaceae
VASC *Monechma cleomoides* (S.Moore) C.B.Clarke — Acanthaceae
VASC *Monechma desertorum* (Engl.) C.B.Clarke — Acanthaceae
VASC *Monechma divaricatum* (Nees) C.B.Clarke — Acanthaceae
VASC *Monechma genistifolium* (Engl.) C.B.Clarke — Acanthaceae
VASC *Monechma genistifolium* (Engl.) C.B.Clarke subsp. *genistifolium* — Acanthaceae
VASC *Monechma genistifolium* subsp. *australe* (P.G.Mey.) Munday — Acanthaceae
VASC *Monechma grandiflorum* Schinz — Acanthaceae
VASC *Monechma mollissimum* (Nees) P.G.Mey. — Acanthaceae
VASC *Monechma spartioides* (T.Anderson) C.B.Clarke — Acanthaceae
VASC *Monelytrum luederitzianum* Hack. — Poaceae
VASC *Monilaria chrysoleuca* (Schltr.) Schwantes — Aizoaceae
VASC *Monilaria moniliformis* (Thunb.) Ihlenf. & Jörg. — Aizoaceae
VASC *Monilaria scutata* (L.Bolus) Schwantes subsp. *scutata* — Aizoaceae
VASC *Monopsis debilis* (L.f.) C.Presl — Lobeliaceae
VASC *Monopsis debilis* var. *gracilis* (C.Presl) Phillipson — Lobeliaceae
VASC *Monopsis lutea* (L.) Urb. — Lobeliaceae
VASC *Monopsis variifolia* (Sims) Urb. — Lobeliaceae
VASC *Monsonia angustifolia* E.Mey. ex A.Rich. — Geraniaceae
VASC *Monsonia luederitziana* Focke & Schinz — Geraniaceae
VASC *Monsonia parvifolia* Schinz — Geraniaceae
VASC *Monsonia senegalensis* Guill. & Perr. — Geraniaceae
VASC *Monsonia speciosa* L. — Geraniaceae

VASC	*Monsonia umbellata* Harv. — Geraniaceae
VASC	*Montinia caryophyllacea* Thunb. — Montiniaceae
VASC	*Moraea angulata* Goldblatt — Iridaceae
VASC	*Moraea angusta* (Thunb.) Ker Gawl. — Iridaceae
VASC	*Moraea bifida* (L.Bolus) Goldblatt — Iridaceae
VASC	*Moraea bituminosa* (L.f.) Ker Gawl. — Iridaceae
VASC	*Moraea deserticola* Goldblatt — Iridaceae
VASC	*Moraea falcifolia* Klatt — Iridaceae
VASC	*Moraea fugacissima* (L.f.) Goldblatt — Iridaceae
VASC	*Moraea fugax* (D.Delaroche) Jacq. — Iridaceae
VASC	*Moraea galaxia* (L.f.) Goldblatt & J.C.Manning — Iridaceae
VASC	*Moraea gawleri* Spreng. — Iridaceae
VASC	*Moraea inconspicua* Goldblatt — Iridaceae
VASC	*Moraea lugubris* (Salisb.) Goldblatt — Iridaceae
VASC	*Moraea miniata* Andrews — Iridaceae
VASC	*Moraea minor* Eckl. — Iridaceae
VASC	*Moraea papilionacea* (L.f.) Ker Gawl. — Iridaceae
VASC	*Moraea pendula* (Goldblatt) Goldblatt — Iridaceae
VASC	*Moraea serpentina* Baker — Iridaceae
VASC	*Moraea tripetala* (L.f.) Ker Gawl. — Iridaceae
VASC	*Moraea tulbaghensis* L.Bolus — Iridaceae
VASC	*Moraea viscaria* (L.f.) Ker Gawl. — Iridaceae
VASC	*Morella humilis* (Cham. & Schltdl.) Killick — Myricaceae
VASC	*Morella quercifolia* (L.) Killick — Myricaceae
AVES	*Motacilla capensis* Linnaeus, 1766 — Motacillidae
VASC	*Mundulea sericea* (Willd.) A.Chev. — Fabaceae
VASC	*Muraltia alopecuroides* (L.) DC. — Polygalaceae
VASC	*Muraltia brevicornu* DC. — Polygalaceae
VASC	*Muraltia ericoides* (Burm.f.) Steud. — Polygalaceae
VASC	*Muraltia filiformis* (Thunb.) DC. — Polygalaceae
VASC	*Muraltia heisteria* (L.) DC. — Polygalaceae
VASC	*Muraltia satureioides* DC. — Polygalaceae
VASC	*Muraltia thunbergii* Eckl. & Zeyh. — Polygalaceae
VASC	*Muraltia thymifolia* (Thunb.) DC. — Polygalaceae
MAM	*Mus indutus* (Thomas, 1910) — Muridae
AVES	*Muscicapa striata* (Pallas, 1764) — Muscicapidae
INSE	*Mylothris agathina agathina* (Cramer, 1779) — Pieridae
AVES	*Myrmecocichla formicivora* Vieillot, 1818 — Muscicapidae
VASC	*Myrovernix scaber* (L.f.) Koekemoer — Asteraceae
VASC	*Myrsine africana* L. — Myrsinaceae
VASC	*Myxopappus hereroensis* (O.Hoffm.) Källersjö — Asteraceae
INSE	*Nabis capsiformis* (Germar, 1838) — Nabidae
REPT	*Naja nivea* Linnaeus, 1758 — Elapidae
INSE	*Naphiellus dilutus* (Horváth, 1892) — Rhyparochromidae
INSE	*Naphius apicalis* (Dallas, 1852) — Rhyparochromidae
INSE	*Nariscus cinctiventris* (Germar, 1838) — Alydidae
INSE	*Nariscus spinosus* (Burmeister, 1835) — Alydidae
AVES	*Nectarinia famosa* (Linnaeus, 1766) — Nectariniidae
AVES	*Nectarinia mariquensis* (A.Smith, 1836) — Nectariniidae
AVES	*Nectarinia senegalensis* (Linnaeus, 1766) — Nectariniidae
AVES	*Nectarinia talatala* (A.Smith, 1836) — Nectariniidae
VASC	*Nelsia quadrangula* (Engl.) Schinz — Amaranthaceae
INSE	*Nemausus inornatus* Stål, 1858 — Alydidae
INSE	*Nemausus sordidatus* (Stål, 1858) — Alydidae
VASC	*Nemesia affinis* Benth. — Scrophulariaceae
VASC	*Nemesia anisocarpa* E.Mey. ex Benth. — Scrophulariaceae
VASC	*Nemesia barbata* (Thunb.) Benth. — Scrophulariaceae
VASC	*Nemesia cheiranthus* E.Mey. ex Benth. — Scrophulariaceae
VASC	*Nemesia ligulata* E.Mey. ex Benth. — Scrophulariaceae
VASC	*Nemesia versicolor* E.Mey. ex Benth. — Scrophulariaceae
VASC	*Nenax acerosa* Gaertn. — Rubiaceae
VASC	*Nenax hirta* (Cruse) Salter — Rubiaceae
LICH	*Neofuscelia namibiensis* Elix & T.H. Nash — Parmeliaceae
VASC	*Neorautanenia amboensis* Schinz — Fabaceae
VASC	*Neorautanenia mitis* (A.Rich.) Verdc. — Fabaceae
AVES	*Neotis ludwigii* (Rüppell, 1837) — Otididae
INSE	*Neotrichedocla quadrisignata* (Stål, 1855) — Reduviidae
INSE	*Nesciothemis farinosa* (Förster, 1898) — Libellulidae
INSE	*Nesciothemis minor* Gambles, 1966 — Libellulidae
VASC	*Nestlera biennis* (Jacq.) Spreng. — Asteraceae
VASC	*Neurada procumbens* Linn. — Neuradaceae
INSE	*Neurogomphus* (*Mastigogomphus*) Cammaerts, 2004 — Gomphidae
INSE	*Neurogomphus cocytius* Cammaerts, 2004 — Gomphidae
INSE	*Neurogomphus zambeziensis* Cammaerts, 2004 — Gomphidae
VASC	*Nicolasia stenoptera* (O.Hoffm.) Merxm. — Asteraceae
VASC	*Nicotiana glauca Graham* — Solanaceae
VASC	*Nidorella resedifolia DC.* — Asteraceae
VASC	*Nidorella resedifolia* DC. subsp. *resedifolia* — Asteraceae
VASC	*Nolletia arenosa* O.Hoffm. — Asteraceae
VASC	*Nolletia tenuifolia* Mattf. — Asteraceae
INSE	*Nortonia* Saussure, 1869 — Eumenidae
INSE	*Notogomphus praetorius* (Selys, 1878) — Gomphidae
AVES	*Numida meleagris* (Linnaeus, 1758) — Numididae
VASC	*Nylandtia spinosa* (L.) Dumort. — Polygalaceae
VASC	*Nymania capensis* (Thunb.) Lindb. — Meliaceae
VASC	*Nymphaea nouchali* Burm.f. — Nymphaeaceae
INSE	*Nysius ericae* (Schilling, 1829) — Lygaeidae
INSE	*Oannes spinosus* Distant, 1911 — Coreidae
VASC	*Ochna cinnabarina* Engl. & Gilg. — Ochnaceae
VASC	*Ochna pulchra* Hook.f. — Ochnaceae
INSE	*Ochrodia pentamacula* (Janse, 1958) — Gelechiidae
INSE	*Ochrodia subdiminutella* (Stainton, 1867) — Gelechiidae
VASC	*Ocimum americanum* L. — Lamiaceae
VASC	*Ocimum americanum* L. var. *americanum* — Lamiaceae
MAM	*Octodon degus* (Molina, 1782) — Octodontidae
VASC	*Octopoma connatum* (L.Bolus) L.Bolus — Aizoaceae
INSE	*Odontotermes* Holmgren, 1912 — Termitidae
INSE	*Odontotermes okahandjae* Fuller, 1922 — Termitidae
VASC	*Oedera capensis* (L.) Druce — Asteraceae
VASC	*Oedera imbricata* Lam. — Asteraceae
VASC	*Oedera sedifolia* (DC.) Anderb. & K.Bremer — Asteraceae
VASC	*Oedera silicicola* (K.Bremer) Anderb. & K.Bremer — Asteraceae
AVES	*Oena capensis* (Linneaus, 1766) — Columbidae
AVES	*Oenanthe monticola* Vieilott, 1818 — Muscicapidae
AVES	*Oenanthe pileata* (Gmelin, 1789) — Muscicapidae
VASC	*Oftia africana* (L.) Bocq. — Scrophulariaceae
VASC	*Olea capensis* L. — Oleaceae
VASC	*Olea europaea* L. — Oleaceae
VASC	*Olea europaea* subsp. *africana* (Mill.) P. S. Green — Oleaceae
VASC	*Oligomeris dipetala* (Aiton) Turcz. — Resedaceae
INSE	*Olpogastra lugubris* Karsch, 1895 — Libellulidae
INSE	*Oncocephalus clavipes* Hesse, 1925 — Reduviidae
VASC	*Oncosiphon grandiflorum* (Thunb.) Källersjö — Asteraceae
VASC	*Oncosiphon piluliferum* (L.f.) Källersjö — Asteraceae
VASC	*Oncosiphon suffruticosum* (L.) Källersjö — Asteraceae
INSE	*Oncylocotis nasutus* (Stål, 1856) — Enicocephalidae
VASC	*Ondetia linearis* Benth. — Asteraceae
VASC	*Onixotis stricta* (Burm.f.) Wijnands — Colchicaceae
AVES	*Onychognathus nabouroup* (Daudin, 1800) — Sturnidae
VASC	*Oophytum nanum* (Schltr.) L.Bolus — Aizoaceae
VASC	*Oophytum oviforme* (N.E.Br.) N.E.Br. — Aizoaceae
LICH	*Opegrapha varia* Pers. — Roccellaceae
VASC	*Ophioglossum lancifolium* C.Presl. — Ophioglossaceae
VASC	*Ophioglossum polyphyllum* A.Braun — Ophioglossaceae
VASC	*Ophioglossum reticulatum* L. — Ophioglossaceae
INSE	*Opistholeptus elegans* (Hesse, 1925) — Pachygronthidae
INSE	*Opistholeptus pallidus* (Hesse, 1925) — Pachygronthidae
INSE	*Oraidium barberae* (Trimen, 1868) — Lycaenidae
VASC	*Orbea lutea* subsp. *vaga* (N.E.Br.) Bruyns — Apocynaceae
VASC	*Orbea namaquensis* (N.E.Br.) L.C.Leach — Apocynaceae
AVES	*Oriolus auratus* Vieillot, 1817 — Oriolidae
INSE	*Orius albidipennis* (Reuter, 1884) — Anthocoridae
INSE	*Ornativalva kalahariensis* Janse, 1960 — Gelechiidae
VASC	*Ornithagalum dubium* Houtt. — Hyacinthaceae
VASC	*Ornithagalum rupestre* L.f. — Hyacinthaceae
VASC	*Ornithogalum concordianum* (Baker) U.& D. Müll.-Doblies — Hyacinthaceae
VASC	*Ornithogalum decusmontium* G.Will. — Hyacinthaceae
VASC	*Ornithogalum dregeanum* Kunth — Hyacinthaceae
VASC	*Ornithogalum graminifolium* Thunb. — Hyacinthaceae
VASC	*Ornithogalum hispidum* Hornem. — Hyacinthaceae
VASC	*Ornithogalum hispidum* Hornem. subsp. *hispidum* — Hyacinthaceae
VASC	*Ornithogalum polyphyllum* Jacq. — Hyacinthaceae
VASC	*Ornithogalum pruinosum* F.M.Leight. — Hyacinthaceae
VASC	*Ornithogalum psammophorum* U.Müll.-Doblies & D.Müll.-Doblies — Hyacinthaceae
VASC	*Ornithogalum secundum* Jacq. — Hyacinthaceae

VASC	*Ornithogalum stapffii* Schinz — Hyacinthaceae
VASC	*Ornithogalum suaveolens* Jacq. — Hyacinthaceae
VASC	*Ornithogalum thyrsoides* Jacq. — Hyacinthaceae
VASC	*Ornithogalum xanthochlorum* Baker — Hyacinthaceae
VASC	*Ornithoglossum calcicola* K.Krause & Dinter — Colchicaceae
VASC	*Ornithoglossum parviflorum* B.Nord. — Colchicaceae
VASC	*Ornithoglossum undulatum* Sweet — Colchicaceae
VASC	*Ornithoglossum viride* (L.f.) Aiton — Colchicaceae
VASC	*Ornithoglossum vulgare* B.Nord. — Colchicaceae
VASC	*Oropetium capense* Stapf — Poaceae
VASC	*Orphium frutescens* (L.) E.Mey — Gentianaceae
VASC	*Orthanthera albida* Shinz — Apocynaceae
VASC	*Orthanthera jasminiflora* (Decne.) Schinz — Apocynaceae
INSE	*Orthetrum abbotti* Calvert, 1892 — Libellulidae
INSE	*Orthetrum brachiale* (Palisot de Beauvois, 1817) — Libellulidae
INSE	*Orthetrum caffrum* (Burmeister, 1839) — Libellulidae
INSE	*Orthetrum chrysostigma* (Burmeister, 1839) — Libellulidae
INSE	*Orthetrum guineense* Ris, 1910 — Libellulidae
INSE	*Orthetrum hintzi* Schmidt, 1951 — Libellulidae
INSE	*Orthetrum icteromelas cinctifrons* Pinhey, 1970 — Libellulidae
INSE	*Orthetrum julia capicola* Kimmins, 1957 — Libellulidae
INSE	*Orthetrum julia falsum* Longfield, 1955 — Libellulidae
INSE	*Orthetrum machadoi* Longfield, 1955 — Libellulidae
INSE	*Orthetrum robustum* Balinsky, 1965 — Libellulidae
INSE	*Orthetrum rubens* Barnard, 1937 — Libellulidae
INSE	*Orthetrum stemmale* (Burmeister, 1839) — Libellulidae
INSE	*Orthetrum trinacria* (Selys, 1841) — Libellulidae
MAM	*Orycteropus afer* (Pallas, 1766) — Orycteropodidae
MAM	*Oryx gazella gazella* (Linneaus, 1758) — Bovidae
VASC	*Oryza longistaminata* Chev. et Roehr — Poaceae
VASC	*Osteospermum armatum* T.Norl. — Asteraceae
VASC	*Osteospermum karrooicum* (Bolus) Norl. — Asteraceae
VASC	*Osteospermum muricatum* E.Mey. ex DC. subsp. *muricatum* — Asteraceae
VASC	*Osteospermum pinnatum* (Thunb.) Norl. var. *pinnatum* — Asteraceae
VASC	*Osteospermum polygaloides* L. — Asteraceae
VASC	*Osteospermum rigidum* Aiton — Asteraceae
VASC	*Osteospermum rigidum* Aiton var. *rigidum* — Asteraceae
VASC	*Osyris compressa* (P.J.Bergius) A. DC. — Santalaceae
INSE	*Othinosmia* Michener, 1943 — Megachilidae
VASC	*Otholobium argenteum* (Thunb.) C.H.Stirt. — Fabaceae
VASC	*Otholobium bolusii* (H.M.L.Forbes) C.H.Stirt. — Fabaceae
VASC	*Othonna abrotanifolia* (Harv.) Druce — Asteraceae
VASC	*Othonna arbuscula* (Thunb.) Sch.Bip. — Asteraceae
VASC	*Othonna bulbosa* L. — Asteraceae
VASC	*Othonna cakilifolia* DC. — Asteraceae
VASC	*Othonna cuneata* DC. — Asteraceae
VASC	*Othonna cylindrica* (Lam.) DC. — Asteraceae
VASC	*Othonna dentata* L. — Asteraceae
VASC	*Othonna digitata* L. — Asteraceae
VASC	*Othonna furcata* (Lindl.) Druce — Asteraceae
VASC	*Othonna hallii* B.Nord. — Asteraceae
VASC	*Othonna hederifolia* B.Nord. — Asteraceae
VASC	*Othonna heterophylla* L.f. — Asteraceae
VASC	*Othonna incisa* Harv. — Asteraceae
VASC	*Othonna intermedia* Compton — Asteraceae
VASC	*Othonna oleracea* Compton — Asteraceae
VASC	*Othonna opima* Merxm. — Asteraceae
VASC	*Othonna pinnata* L.f. — Asteraceae
VASC	*Othonna protecta* Dinter — Asteraceae
VASC	*Othonna rechingeri* B.Nord. — Asteraceae
VASC	*Othonna retrorsa* DC. — Asteraceae
VASC	*Othonna sedifolia* DC. — Asteraceae
VASC	*Othonna stenophylla* Levyns — Asteraceae
MAM	*Otocyon megalotis* (Desmarest, 1822) — Canidae
VASC	*Otoptera burchellii* DC. — Fabaceae
AVES	*Otus leucotis* (Temminck, 1820) — Strigidae
AVES	*Otus senegalensis* (Swainson, 1837) — Strigidae
VASC	*Oxalis ambigua* Jacq. — Oxalidaceae
VASC	*Oxalis comosa* E.Mey. ex Sond. — Oxalidaceae
VASC	*Oxalis depressa* Eckl. & Zeyh. — Oxalidaceae
VASC	*Oxalis dregei* Sond. — Oxalidaceae
VASC	*Oxalis flava* L. — Oxalidaceae
VASC	*Oxalis foveolata* Turcz. — Oxalidaceae
VASC	*Oxalis goniorrhiza* Eckl. & Zeyh. — Oxalidaceae
VASC	*Oxalis hirta* L. — Oxalidaceae
VASC	*Oxalis livida* Jacq. — Oxalidaceae
VASC	*Oxalis louisae* T.M.Salter — Oxalidaceae
VASC	*Oxalis luteola* Jacq. — Oxalidaceae
VASC	*Oxalis obtusa* Jacq. — Oxalidaceae
VASC	*Oxalis pes-caprae* L. — Oxalidaceae
VASC	*Oxalis polyphylla* Jacq. — Oxalidaceae
VASC	*Oxalis purpurascens* T.M.Salter — Oxalidaceae
VASC	*Oxalis purpurea* L. — Oxalidaceae
VASC	*Oxalis tomentosa* L.f. — Oxalidaceae
VASC	*Oxalis versicolor* L. — Oxalidaceae
INSE	*Oxycarenus hyalinipennis* (A. Costa, 1847) — Oxycarenidae
VASC	*Oxygonum alatum* Burch. — Polygonaceae
VASC	*Oxygonum alatum* Burch. var. *alatum* — Polygonaceae
VASC	*Oxygonum sinuatum* (Hochst. & Steud. ex Meisn.) — Polygonaceae
INSE	*Ozarba hemisarca* Hampson, 1916 — Noctuidae
VASC	*Ozoroa crassinervia* (Engl.) R.Fern. & A.Fern. — Anacardiaceae
VASC	*Ozoroa dispar* (C.Presl.) R.Fern. & A.Fern. — Anacardiaceae
VASC	*Ozoroa paniculosa* (Sond.) R.Fern. & A.Fern. — Anacardiaceae
VASC	*Ozoroa schinzii* (Engl) R.Fern. & A.Fern. — Anacardiaceae
VASC	*Pachypodium namaquanum* (Wyley ex Harv.) Welw. — Apocynaceae
INSE	*Palasea albimacula* Wallengren, 1863 — Lymantriidae
INSE	*Palpopleura deceptor* (Calvert, 1899) — Libellulidae
INSE	*Palpopleura jucunda jucunda* Rambur, 1842 — Libellulidae
INSE	*Palpopleura lucia* (Drury, 1773) — Libellulidae
INSE	*Palpopleura portia* (Drury, 1773) — Libellulidae
VASC	*Panicum arbusculum* Mez — Poaceae
VASC	*Panicum coloratum* L. — Poaceae
VASC	*Panicum coloratum* L. var. *coloratum* — Poaceae
VASC	*Panicum kalaharense* Mez — Poaceae
VASC	*Panicum lanipes* Mez — Poaceae
VASC	*Panicum maximum* Jacq. — Poaceae
VASC	*Panicum stapfianum* Fourc. — Poaceae
VASC	*Panicum trichonode* Launert & Renvoize — Poaceae
INSE	*Pantala flavescens* (Fabricius, 1798) — Libellulidae
INSE	*Papilio demodocus demodocus* Esper, 1798 — Papilionidae
INSE	*Paragomphus cataractae* Pinhey, 1963 — Gomphidae
INSE	*Paragomphus cognatus* (Rambur, 1842) — Gomphidae
INSE	*Paragomphus elpidius* (Ris, 1921) — Gomphidae
INSE	*Paragomphus genei* (Selys, 1841) — Gomphidae
INSE	*Paragomphus sabicus* Pinhey, 1950 — Gomphidae
INSE	*Paraptica concinerata* Meyrick, 1908 — Tineidae
INSE	*Parazyxomma flavicans* (Martin, 1908) — Libellulidae
AVES	*Parisoma layardi* Hartlaub, 1862 — Sylviidae
AVES	*Parisoma subcaeruleum* (Vieillot, 1817) — Sylviidae
VASC	*Parkinsonia africana* Sond. — Fabaceae
LICH	*Parmotrema austrosinense* (Zahlbr.) Hale — Parmeliaceae
LICH	*Parmotrema eciliatum* (Nyl.) Hale — Parmeliaceae
INSE	*Paromius apicatus* (Stål, 1855) — Rhyparochromidae
INSE	*Paromius gracilis* (Stål, 1855) — Rhyparochromidae
AVES	*Parus afer* J.F.Gmelin, 1789 — Paridae
AVES	*Parus carpi* Macdonald & Hall, 1957 — Paridae
AVES	*Parus cinerascens* Vieillot, 1818 — Paridae
AVES	*Passer diffusus* (A.Smith, 1836) — Passeridae
AVES	*Passer griseus* (Vieillot, 1817) — Passeridae
AVES	*Passer melanurus* (Statius Müller, 1776) — Passeridae
VASC	*Passerina corymbosa* Eckl. ex C.H.Wright — Thymelaeaceae
VASC	*Passerina truncata* (Meisn.) Bredenkamp & A.E. van Wyk subsp. *truncata* — Thymelaeaceae
VASC	*Pavetta zeyheri* Sond. — Rubiaceae
VASC	*Pavonia burchellii* (DC.) R.A.Dyer — Malvaceae
VASC	*Pavonia clathrata* Mast. — Malvaceae
VASC	*Pavonia rehmannii* Szyszyl. — Malvaceae
LICH	*Peccania arabica* (Müll. Arg.) Henssen — Lichinaceae
LICH	*Peccania arizonica* Tuck. ex Herre — Lichinaceae
LICH	*Peccania font-queriana* P.P. Moreno & Egea — Lichinaceae
LICH	*Peccania subnigra* (B. de Lesd.) Wetmore — Lichinaceae
VASC	*Pechuel-loeschea leubnitziae* (Kuntze) O.Hoffm. — Asteraceae
INSE	*Pecticossus gaerdesi* Daniel, 1956 — Cossidae
VASC	*Pectinaria longipes* (N.E.Br.) Bruyns subsp. *longipes* — Apocynaceae

MAM	*Pedetes capensis* (Forster, 1778) — Pedetidae
REPT	*Pedioplanis namaquensis* Duméril & Bibron, 1839 — Lacertidae
VASC	*Pegolettia oxyodonta* DC. — Asteraceae
VASC	*Pegolettia pinnatilobata* (Klatt) O.Hoffm. ex Dinter — Asteraceae
VASC	*Pegolettia senegalensis* Cass. — Asteraceae
INSE	*Peirates strepitans* Rambur, 1839 — Reduviidae
VASC	*Pelargonium capitatum* (L.) L‘Hér. — Geraniaceae
VASC	*Pelargonium carnosum* (L.) L‘Hér — Geraniaceae
VASC	*Pelargonium caroli-henrici* B.Nord. — Geraniaceae
VASC	*Pelargonium chamaedryfolium* Jacq. — Geraniaceae
VASC	*Pelargonium chelidonium* (Houtt.) DC. — Geraniaceae
VASC	*Pelargonium cordifolium* (Cav.) Curtis — Geraniaceae
VASC	*Pelargonium crithmifolium* Sm. — Geraniaceae
VASC	*Pelargonium echinatum* Curtis — Geraniaceae
VASC	*Pelargonium fulgidum* (L.) L‘Hér — Geraniaceae
VASC	*Pelargonium grandicalcaratum* R.Knuth — Geraniaceae
VASC	*Pelargonium grossularioides* (L.) L‘Hér. — Geraniaceae
VASC	*Pelargonium incrassatum* (Andrews) Sims — Geraniaceae
VASC	*Pelargonium karooicum* Compton & P.E.Barnes — Geraniaceae
VASC	*Pelargonium klinghardtense* R.Knuth — Geraniaceae
VASC	*Pelargonium leucophyllum* Turcz. — Geraniaceae
VASC	*Pelargonium longifolium* (Burm.f.) Jacq. — Geraniaceae
VASC	*Pelargonium minimum* (Cav.) Willd. — Geraniaceae
VASC	*Pelargonium multicaule* Jacq. — Geraniaceae
VASC	*Pelargonium myrrhifolium* (L.) L`Hér. — Geraniaceae
VASC	*Pelargonium oenothera* (L.f.) Jacq. — Geraniaceae
VASC	*Pelargonium praemorsum* (Andrews) F.Dietr. — Geraniaceae
VASC	*Pelargonium proliferum* (Burm.f.) Steud. — Geraniaceae
VASC	*Pelargonium pulchellum* Sims — Geraniaceae
VASC	*Pelargonium spinosum* Willd. — Geraniaceae
VASC	*Pelargonium triste* (L.) L‘Hér. — Geraniaceae
INSE	*Peliochrous globisternum* Linnavuori, 1978 — Rhopalidae
INSE	*Peliochrous nigromaculatus* Stål, 1855 — Rhopalidae
VASC	*Peliostomum leucorrhizum* E.Mey. ex Benth. — Scrophulariaceae
VASC	*Peliostomum virgatum* E.Mey. ex Benth. — Scrophulariaceae
VASC	*Pellaea calomelanos* (Sw.) Link — Pteridaceae
INSE	*Pelopidas thrax inconspicua* (Bertoloni, 1858) — Hesperidae
VASC	*Peltophorum africanum* Sond. — Fabaceae
LICH	*Peltula coriacea* Büdel et al. — Peltulaceae
LICH	*Peltula corticola* Büdel & R. Sant. — Peltulaceae
LICH	*Peltula inversa* Büdel & M. Schultz — Peltulaceae
LICH	*Peltula obscurans* (Nyl.) Gyeln. — Peltulaceae
LICH	*Peltula obscurans* var. *deserticola* (Zahlbr.) Wetmore — Peltulaceae
LICH	*Peltula obscurans* var. *hassei* (Zahlbr.) Wetmore — Peltulaceae
LICH	*Peltula omphaliza* (Nyl.) Wetmore — Peltulaceae
LICH	*Peltula patellata* (Bagl.) Swinscow & Krog — Peltulaceae
LICH	*Peltula radicata* Nyl. — Peltulaceae
VASC	*Penaea mucronata* L. — Penaeaceae
VASC	*Pennisetum glaucum* (L.) R.Br. — Poaceae
VASC	*Pennisetum macrourum* Trin. — Poaceae
VASC	*Pentarrhinum insipidum* E.Mey. — Apocynaceae
VASC	*Pentaschistis airoides* (Nees) Stapf — Poaceae
VASC	*Pentaschistis airoides* (Nees) Stapf subsp. *airoides* — Poaceae
VASC	*Pentaschistis barbata* (Nees) H.P.Linder — Poaceae
VASC	*Pentaschistis barbata* (Nees) H.P.Linder subsp. *barbata* — Poaceae
VASC	*Pentaschistis curvifolia* (Schrad.) Stapf — Poaceae
VASC	*Pentaschistis ecklonii* (Nees) McClean — Poaceae
VASC	*Pentaschistis malouinensis* (Steud.) Clayton — Poaceae
VASC	*Pentaschistis pallida* (Thunb.) H.P.Linder — Poaceae
VASC	*Pentaschistis papillosa* (Steud.) H.P.Linder — Poaceae
VASC	*Pentaschistis patula* (Nees) Stapf — Poaceae
VASC	*Pentaschistis tomentella* Stapf — Poaceae
VASC	*Pentaschistis triseta* (Thunb.) Stapf — Poaceae
VASC	*Pentzia argentea* Hutch. — Asteraceae
VASC	*Pentzia calva* S.Moore — Asteraceae
VASC	*Pentzia incana* (Thunb.) Kuntze — Asteraceae
VASC	*Pentzia monocephala* S.Moore — Asteraceae
VASC	*Pentzia peduncularis* B.Nord. — Asteraceae
VASC	*Pentzia pinnatisecta* Hutch. — Asteraceae
INSE	*Pephricus paradoxus* (Sparrmann, 1777) — Coreidae
VASC	*Pergularia daemia* (Forssk.) Chiov. var. *daemia* — Apocynaceae
VASC	*Pergularia daemia* L. — Apocynaceae
VASC	*Peristrophe hereroensis* (Schinz) K.Balkwill — Acanthaceae
VASC	*Peristrophe paniculata* (Forssk.) Brummitt — Acanthaceae
VASC	*Perotis patens* Gand. — Poaceae
VASC	*Perotis vaginata* Hack. — Poaceae
VASC	*Persicaria limbata* (Meisn.) H.Hara — Polygonaceae
LICH	*Pertusaria coccodes* (Ach.) Nyl. — Pertusariaceae
VASC	*Petalacte coronata* (L.) D.Don — Asteraceae
VASC	*Petalidium linifolium* Harv. — Acanthaceae
VASC	*Petalidium setosum* C.B.Clarke ex Schinz — Acanthaceae
LICH	*Phaeophyscia confusa* Moberg — Pertusariaceae
LICH	*Phaeophyscia hispidula* (Ach.) Essl. — Pertusariaceae
LICH	*Phaeophyscia orbicularis* (Neck.) Moberg — Pertusariaceae
VASC	*Phaeoptilum spinosum* Radlk. — Nyctaginaceae
VASC	*Phalaris arundinacea* L. — Poaceae
INSE	*Phaon iridipennis* (Burmeister, 1839) — Calopterygidae
VASC	*Pharnaceum confertum* (DC.) Eckl. & Zeyh. — Molluginaceae
VASC	*Pharnaceum confertum* var. *brachyphyllum* Adamson — Molluginaceae
VASC	*Pharnaceum croceum* E.Mey. ex Fenzl — Molluginaceae
VASC	*Pharnaceum exiguum* Adamson — Molluginaceae
VASC	*Pharnaceum incanum* L. — Molluginaceae
VASC	*Pharnaceum lanatum* Bartl. — Molluginaceae
INSE	*Phasis clavum clavum* Swanepoel, 1953 — Lycaenidae
VASC	*Philenoptera nelsii* (Schinz) Schrire — Fabaceae
AVES	*Philetairus socius* (Latham, 1790) — Ploceidae
INSE	*Philodoxus principalis* (Distant, 1903) — Reduviidae
LICH	*Phloeopeccania pulvinulina* J. Steiner — Lichinaceae
INSE	*Phorticus pulchellus* Reuter, 1882 — Reduviidae
INSE	*Phricodus hystrix* (Germar, 1838) — Pentatomidae
VASC	*Phylica buxifolia* L. — Rhamnaceae
VASC	*Phylica cephalantha* Sond. — Rhamnaceae
VASC	*Phylica cuspidata* Eckl. & Zeyh. — Rhamnaceae
VASC	*Phylica imberbis* P.J.Bergius — Rhamnaceae
VASC	*Phylica plumosa* L. — Rhamnaceae
VASC	*Phylica rogersii* Pillans — Rhamnaceae
VASC	*Phylica strigulosa* Sond. — Rhamnaceae
VASC	*Phyllanthus loandensis* Welw. ex Müll.Arg. — Euphorbiaceae
VASC	*Phyllanthus maderaspatensis* L. — Euphorbiaceae
VASC	*Phyllanthus omahekensis* Dinter & Pax — Euphorbiaceae
VASC	*Phyllanthus pentandrus* Schumach. & Thonn. — Euphorbiaceae
VASC	*Phyllobolus abbreviatus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus congestus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus deciduus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus decurvatus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus herbertii* (N.E.Br.) Gerbaulet — Aizoaceae
VASC	*Phyllobolus melanospermus* (Dinter & Schwantes) Gerbaulet — Aizoaceae
VASC	*Phyllobolus nitidus* (Haw.) Gerbaulet — Aizoaceae
VASC	*Phyllobolus oculatus* (N.E.Br.) Gerbaulet — Aizoaceae
VASC	*Phyllobolus prasinus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus quartziticus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus sinuosus* (L.Bolus) Gerbaulet — Aizoaceae
VASC	*Phyllobolus spinuliferus* (Haw.) Gerbaulet — Aizoaceae
VASC	*Phyllobolus splendens* (L.) Gerbaulet — Aizoaceae
VASC	*Phyllobolus trichotomus* (Thunb.) Gerbaulet — Aizoaceae
INSE	*Phyllogomphus selysii* Schouteden, 1933 — Gomphidae
INSE	*Phyllomacromia contumax* Selys, 1879 — Macromiidae
INSE	*Phyllomacromia kimminsi* (Fraser, 1954) — Macromiidae
INSE	*Phyllomacromia overlaeti* (Schouteden, 1934) — Macromiidae
INSE	*Phyllomacromia picta* (Hagen, 1871) — Macromiidae
VASC	*Phyllopodium cephalophorum* (Thunb.) Hilliard — Scrophulariaceae
VASC	*Phyllopodium cordatum* (Thunb.) Hilliard — Scrophulariaceae
VASC	*Phyllopodium phyllopodioides* (Schltr.) Hilliard — Scrophulariaceae
AVES	*Phylloscopus trochilus* (Linnaeus, 1758) — Phylloscopidae
LICH	*Physcia adscendens* (Th. Fr.) H. Olivier — Physciaceae
LICH	*Physcia erumpens* Moberg — Physciaceae
LICH	*Physcia poncinsii* Hue — Physciaceae
LICH	*Physcia undulata* Moberg — Physciaceae
INSE	*Piezodorus purus* Stål, 1853 — Pentatomidae
INSE	*Pinacopteryx eriphia eriphia* (Godart, 1819) — Pieridae

INSE	*Pinheyagrion angolicum* (Pinhey, 1966) — Coenagrionidae
LICH	*Placidium lacinulatum* (Ach.) Breuss — Verrucariaceae
LICH	*Placidium semaforonense* (Breuss) Breuss — Verrucariaceae
LICH	*Placidium squamulosum* (Ach.) Breuss — Verrucariaceae
LICH	*Placidium tenellum* (Breuss) Breuss — Verrucariaceae
VASC	*Plantago cafra* Decne. — Plantaginaceae
VASC	*Platycarpha carlinoides* Oliv. & Hiern — Asteraceae
INSE	*Platycypha caligata* (Selys, 1853) — Chlorocyphidae
INSE	*Platycypha fitzsimonsi* (Pinhey, 1950) — Chlorocyphidae
INSE	*Platymeris biguttatus* Linnaeus, 1767 — Reduviidae
VASC	*Plinthus sericeus* Pax — Aizoaceae
AVES	*Plocepasser mahali* Smith, 1836 — Passeridae
AVES	*Ploceus capensis* (Linnaeus, 1766) — Ploceidae
AVES	*Ploceus intermedius* Rüppell, 1849 — Ploceidae
AVES	*Ploceus velatus* Vieilott, 1819 — Ploceidae
VASC	*Plukenetia africana* Sond. — Euphorbiaceae
VASC	*Poggea longepedunculata* Bamps — Flacourtiaceae
VASC	*Pogonarthria fleckii* (Hack.) Hack. — Poaceae
VASC	*Pogonarthria leiarthra* Hack. — Poaceae
VASC	*Pogonarthria squarrosa* (Roem. & Schult.) Pilg. — Poaceae
AVES	*Polihierax semitorquatus* (A.Smith, 1836) — Falconidae
VASC	*Pollichia campestris* Aiton — Caryophyllaceae
VASC	*Polpoda capensis* C.Presl — Molluginaceae
VASC	*Polpoda stipulacea* (F.M.Leight.) Adamson — Molluginaceae
VASC	*Polycarena gilioides* Benth. — Scrophulariaceae
VASC	*Polycarpaea corymbosa* (L.) Lam. — Caryophyllaceae
VASC	*Polygala albida* Schinz — Polygalaceae
VASC	*Polygala bracteolata* L. — Polygalaceae
VASC	*Polygala garcinii* DC. — Polygalaceae
VASC	*Polygala lehmanniana* Eckl. & Zeyh. — Polygalaceae
VASC	*Polygala leptophylla* Burch. — Polygalaceae
VASC	*Polygala mossii* Exell — Polygalaceae
VASC	*Polygala schinziana* Chodat — Polygalaceae
VASC	*Polygala virgata* Thunb. — Polygalaceae
VASC	*Polygonum kitaibelianum* Sadler — Polygonaceae
VASC	*Polymita albiflora* (L.Bolus) L.Bolus — Aizoaceae
VASC	*Polymita steenbokensis* H.E.K.Hartmann — Aizoaceae
VASC	*Polypogon monspeliensis* (L.) Desf. — Poaceae
INSE	*Pontia helice helice* (Linnaeus, 1764) — Pieridae
LICH	*Porocyphus coccodes* (Flot.) Körb. — Lichinaceae
VASC	*Portulaca hereroensis* Schinz — Portulacaceae
VASC	*Portulaca kermesina* N.E.Br. — Portulacaceae
VASC	*Portulaca oleracea* L. — Portulacaceae
VASC	*Portulaca quadrifida* L. — Portulacaceae
VASC	*Prenia pallens* subsp. *lancea* (Thunb.) Gerbaulet — Aizoaceae
VASC	*Prenia sladeniana* (L.Bolus) L.Bolus — Aizoaceae
VASC	*Prenia tetragona* (Thunb.) Gerbaulet — Aizoaceae
AVES	*Prinia flavicans* (Vieillot, 1820) — Cisticolidae
AVES	*Prinia maculosa* (Boddaert, 1783) — Cisticolidae
AVES	*Prinia subflava* (J.F.Gmelin, 1789) — Cisticolidae
AVES	*Prionops plumatus* (Shaw, 1809) — Prionopidae
AVES	*Pririt batis* (Vieillot, 1818) — Platysteiridae
VASC	*Prismatocarpus campanuloides* (L.f.) Sond. var. *campanuloides* — Campanulaceae
VASC	*Prismatocarpus sessilis* Eckl. ex A. DC. — Campanulaceae
MAM	*Procavia capensis* (Pallas, 1766) — Procaviidae
INSE	*Proischnura polychromatica* (Barnard, 1937) — Coenagrionidae
INSE	*Proischnura subfurcata* (Selys, 1876) — Coenagrionidae
INSE	*Promirotermes* Silvestri, 1914 — Termitidae
VASC	*Prosopis glandulosa* Torrey — Fabaceae
VASC	*Protea acaulos* (L.) Reichard — Proteaceae
VASC	*Protea burchellii* Stapf — Proteaceae
VASC	*Protea cynaroides* (L.) L. — Proteaceae
VASC	*Protea mucronifolia* Salisb. — Proteaceae
VASC	*Protea scolymocephala* (L.) Reichard — Proteaceae
REPT	*Psammobates tentorius verroxii* (Smith, 1839) — Testudinidae
REPT	*Psammophis leightoni trinasalis* Werner, 1902 — Colubridae
INSE	*Psammotermes allocerus* Silvestri, 1908 — Rhinotermitidae
VASC	*Psammotropha spicata* Adamson — Molluginaceae
INSE	*Pseudagrion acaciae* Förster, 1906 — Coenagrionidae
INSE	*Pseudagrion assegaii* Pinhey, 1950 — Coenagrionidae
INSE	*Pseudagrion citricola* Barnard, 1937 — Coenagrionidae
INSE	*Pseudagrion coeleste* Longfield, 1947 — Coenagrionidae
INSE	*Pseudagrion commoniae nigerrimum* Pinhey, 195 — Coenagrionidae
INSE	*Pseudagrion deningi* Pinhey, 1961 — Coenagrionidae
INSE	*Pseudagrion draconis* Barnard, 1937 — Coenagrionidae
INSE	*Pseudagrion fisheri* Pinhey, 1961 — Coenagrionidae
INSE	*Pseudagrion furcigerum* (Rambur, 1842) — Coenagrionidae
INSE	*Pseudagrion glaucescens* Selys, 1876 — Coenagrionidae
INSE	*Pseudagrion hageni* Karsch, 1893 — Coenagrionidae
INSE	*Pseudagrion hamoni* Fraser, 1955 — Coenagrionidae
INSE	*Pseudagrion helenae* Balinsky, 1964 — Coenagrionidae
INSE	*Pseudagrion inconspicuum* Ris, 1931 — Coenagrionidae
INSE	*Pseudagrion kersteni* (Gerstäcker, 1869) — Coenagrionidae
INSE	*Pseudagrion massaicum* Sjöstedt, 1909 — Coenagrionidae
INSE	*Pseudagrion nubicum* Selys, 1871 — Coenagrionidae
INSE	*Pseudagrion rufostigma* Longfield, 1947 — Coenagrionidae
INSE	*Pseudagrion salisburyense* Ris, 1921 — Coenagrionidae
INSE	*Pseudagrion sloestedti jacksoni* Pinhey, 1961 — Coenagrionidae
INSE	*Pseudagrion spernatum* Hagen in Selys, 1881 — Coenagrionidae
INSE	*Pseudagrion sublacteum* (Karsch, 1893) — Coenagrionidae
INSE	*Pseudagrion sudanicum rubroviride* Pinhey, 1955 — Coenagrionidae
INSE	*Pseudagrion vaalense* Chutter, 1962 — Coenagrionidae
VASC	*Pseudogaltonia clavata* (Mast.) E.Phillips — Hyacinthaceae
VASC	*Pseudolachnostylis maprouneifolia* Pax — Euphorbiaceae
VASC	*Pseudopentameris macrantha* (Schrad.) Conert — Poaceae
VASC	*Pseudoschoenus inanis* (Thunb.) Oteng-Yeb. — Cyperaceae
VASC	*Pseudoselago rapunculoides* (L.) Hilliard — Scrophulariaceae
VASC	*Pseudoselago spuria* (L.) Hilliard — Scrophulariaceae
INSE	*Pseudozarba schencki* (Strand, 1912) — Noctuidae
VASC	*Psilocaulon articulatum* (Thunb.) N.E.Br. — Aizoaceae
VASC	*Psilocaulon dinteri* (Engl.) Schwantes — Aizoaceae
VASC	*Psilocaulon foliosum* L.Bolus — Aizoaceae
VASC	*Psilocaulon leptarthron* (A.Berger) N.E.Br. — Aizoaceae
VASC	*Psilocaulon salicornioides* (Pax) Schwantes — Aizoaceae
VASC	*Psilocaulon subnodosum* (A.Berger) N.E.Br. — Aizoaceae
AVES	*Psophocichla litsipsirupa* (A.Smith, 1836) — Hirundinidae
LICH	*Psora* aff. *cerebriformis* W.A. Weber — Psoraceae
LICH	*Psora crenata* (Taylor) Reinke — Psoraceae
VASC	*Psora decipiens* (Hedw.) Hoffm. — Psoraceae
LICH	*Psorotichia frustulosa* Anzi — Lichinaceae
LICH	*Psorotichia hassei* Fink ex J. Hedrick — Lichinaceae
VASC	*Psydrax livida* (Hiern) Bridson — Rubiaceae
REPT	*Ptenopus garrulus* (Smith, 1879) — Gekkonidae
VASC	*Pterocarpus angolensis* DC. — Fabaceae
VASC	*Pterocarpus lucens* subsp. *antunesii* (Taub.) Rojo — Fabaceae
VASC	*Pterocelastrus tricuspidatus* (Lam.) Walp. — Celastraceae
AVES	*Pterocles bicinctus* Temminck, 1815 — Pteroclididae
AVES	*Pterocles namaqua* (J.F.Gmelin, 1789) — Pteroclididae
VASC	*Pterodiscus aurantiacus* Welw. — Pedaliaceae
VASC	*Pterodiscus ngamicus* N.E.Br. ex Stapf — Pedaliaceae
VASC	*Pteronia acuminata* DC. — Asteraceae
VASC	*Pteronia camphorata* (L.) L. — Asteraceae
VASC	*Pteronia camphorata* (L.) L. var. *camphorata* — Asteraceae
VASC	*Pteronia ciliata* Thunb. — Asteraceae
VASC	*Pteronia divaricata* (P.J.Bergius) Less. — Asteraceae
VASC	*Pteronia fastigiata* Thunb. — Asteraceae
VASC	*Pteronia glabrata* L.f. — Asteraceae
VASC	*Pteronia glauca* Thunb. — Asteraceae
VASC	*Pteronia glomerata* L.f. — Asteraceae
VASC	*Pteronia heterocarpa* DC. — Asteraceae
VASC	*Pteronia incana* (Burm.) DC. — Asteraceae
VASC	*Pteronia leptospermoides* DC. — Asteraceae
VASC	*Pteronia lucilioides* DC. — Asteraceae
VASC	*Pteronia mucronata* DC. — Asteraceae
VASC	*Pteronia oblanceolata* E.Phillips — Asteraceae
VASC	*Pteronia onobromoides* DC. — Asteraceae
VASC	*Pteronia paniculata* Thunb. — Asteraceae
VASC	*Pteronia scariosa* L.f. — Asteraceae
VASC	*Pteronia undulata* DC. — Asteraceae
VASC	*Pteronia villosa* DC. — Asteraceae
VASC	*Pterygodium caffrum* (L.) Sw. — Orchidaceae
VASC	*Pterygodium catholicum* (L.) Sw. — Orchidaceae
VASC	*Ptycholobium biflorum* (E.Mey.) Brummitt — Fabaceae

VASC	*Ptycholobium biflorum* (E.Mey.) Brummitt subsp. *biflorum* — Fabaceae
VASC	*Ptycholobium biflorum* subsp. *angolensis* (Baker) Brummitt — Fabaceae
AVES	*Ptyonoprogne fuligula* (Lichtenstein, 1842) — Hirundinidae
VASC	*Pupalia lappacea* (L.) A.Juss. — Amaranthaceae
VASC	*Pupalia lappacea* (L.) A.Juss. var. *lappacea* — Amaranthaceae
VASC	*Putterlickia pyracantha* (L.) Szyszyl. — Celastraceae
AVES	*Pycnonotus barbatus* (Desfontaines, 1789) — Pycnonotidae
AVES	*Pycnonotus capensis* (Linnaeus, 1766) — Pycnonotidae
AVES	*Pycnonotus nigricans* (Vieillot, 1818) — Pycnonotidae
VASC	*Pycreus chrysanthus* (Boeck.) C.B.Clarke — Cyperaceae
VASC	*Pycreus macrostachyos* (Lam.) J.Raynal — Cyperaceae
INSE	*Pyncostola iospila* (Meyrick, 1909) — Gelechiidae
AVES	*Pytilia melba* (Linneaus, 1758) — Estrildidae
LICH	*Pyxine cocoës* (Sw.) Nyl. — Physciaceae
LICH	*Pyxine nubila* Moberg — Physciaceae
LICH	*Pyxine petricola* Nyl. — Physciaceae
VASC	*Quaqua incarnata* (L.f.) Bruyns — Apocynaceae
VASC	*Quaqua mammillaris* (L.) Bruyns — Apocynaceae
VASC	*Quaqua pruinosa* (Masson) Bruyns — Apocynaceae
INSE	*Quartinia conchicola* Gess, 2007 — Vespidae
INSE	*Quartinia* Ed. André, 1884 — Vespidae
INSE	*Quartinia refugicola* Gess, 2007 — Vespidae
INSE	*Quartinia vagepunctata* Schulthess, 1929 — Vespidae
INSE	*Quartinoides* Richards, 1962 — Vespidae
VASC	*Rafnia crassifolia* Harv. — Fabaceae
VASC	*Rafnia diffusa* Thunb. — Fabaceae
LICH	*Ramalina canariensis* J. Steiner — Ramalinaceae
LICH	*Ramalina capensis* Th. Fr. — Ramalinaceae
LICH	*Ramalina celastri* (Spreng.) Krog & Swinscow — Ramalinaceae
LICH	*Ramalina* aff. *implectens* Nyl. — Ramalinaceae
LICH	*Ramalina lacera* (With.) J. R. Laundon — Ramalinaceae
MAM	*Raphicerus campestris* (Thunberg, 1811) — Bovidae
VASC	*Raphionacme lanceolata* Schinz — Apocynaceae
VASC	*Raphionacme velutina* Schltr. — Apocynaceae
INSE	*Reduvius nigricephalus* Hesse, 1925 — Reduviidae
INSE	*Reduvius sorex* Miller, 1955 — Reduviidae
INSE	*Reduvius tarsatus* Germar, 1838 — Reduviidae
VASC	*Reissantia parviflora* (N.E.Br.) N.Halle — Celastraceae
VASC	*Relhania fruticosa* (L.) K.Bremer — Asteraceae
VASC	*Relhania fruticosa* (L.) Bremer — Asteraceae
VASC	*Relhania rotundifolia* Less. — Asteraceae
VASC	*Requienia pseudosphaerosperma* (Schinz) Brummitt — Fabaceae
VASC	*Requienia sphaerosperma* DC. — Fabaceae
VASC	*Restio ambiguus* Mast. — Restionaceae
VASC	*Restio bifurcus* Mast. — Restionaceae
VASC	*Restio dodii* Pillans — Restionaceae
VASC	*Restio filiformis* Poir. — Restionaceae
VASC	*Restio micans* Nees — Restionaceae
VASC	*Restio multiflorus* Spreng. — Restionaceae
VASC	*Restio quadratus* Mast. — Restionaceae
VASC	*Restio quinquefarius* Nees — Restionaceae
MAM	*Rhabdomys pumilio* (Sparrman, 1784) — Muridae
INSE	*Rhadinotermes coarctatus* (Sjöstedt, 1902) — Termitidae
INSE	*Rhaphidosoma rhodesiae* Miller, 1956 — Reduviidae
INSE	*Rhaphidosoma simoni* Jeannel, 1914 — Reduviidae
VASC	*Rhigozum brevispinosum* Kuntze — Bignoniaceae
VASC	*Rhigozum trichotomum* Burch. — Bignoniaceae
AVES	*Rhinopomastus cyanomelas* (Vieillot, 1819) — Phoeniculidae
VASC	*Rhus glauca* Thunb. — Anacardiaceae
VASC	*Rhus incisa* L.f. — Anacardiaceae
VASC	*Rhus laevigata* L. — Anacardiaceae
VASC	*Rhus laevigata* L. var. *laevigata* — Anacardiaceae
VASC	*Rhus laevigata* var. *villosa* (L.f.) R.Fern. — Anacardiaceae
VASC	*Rhus lancea* L.f. — Anacardiaceae
VASC	*Rhus lucida* L. — Anacardiaceae
VASC	*Rhus lucida* L.f. *lucida* — Anacardiaceae
VASC	*Rhus marlothii* Engl. — Anacardiaceae
VASC	*Rhus populifolia* E.Mey. ex Sond. — Anacardiaceae
VASC	*Rhus rosmarinifolia* Vahl — Anacardiaceae
VASC	*Rhus tenuinervis* Engl. — Anacardiaceae
VASC	*Rhus undulata* Jacq. — Anacardiaceae
VASC	*Rhynchopsidium pumilum* (L.f.) DC. — Asteraceae
VASC	*Rhynchosia holosericea* Schinz — Fabaceae
VASC	*Rhynchosia minima* (L.) DC. — Fabaceae
VASC	*Rhynchosia minima* (L.) DC. var. *minima* — Fabaceae
VASC	*Rhynchosia sublobata* (Schumach.) Meikle — Fabaceae
VASC	*Rhynchosia totta* (Thunb.) DC. — Fabaceae
VASC	*Rhynchosia totta* (Thunb.) DC. var. *totta* — Fabaceae
VASC	*Rhynchosia vendae* C.H.Stirt. — Fabaceae
VASC	*Rhynchosia venulosa* (Hiern) K.Schum. — Fabaceae
INSE	*Rhyothemis fenestrina* (Rambur, 1842) — Libellulidae
INSE	*Rhyothemis mariposa* Ris, 1913 — Libellulidae
INSE	*Rhyothemis semihyalina* (Desjardins, 1832) — Libellulidae
LICH	*Rinodina boleana* Giralt & H. Mayrhofer — Physciaceae
LICH	*Rinodina capensis* Hampe — Physciaceae
LICH	*Rinodina furfuracea* H. Magn. — Physciaceae
LICH	*Rinodina gennari* Bagl. — Physciaceae
LICH	*Rinodina longisperma* Matzer & H. Mayrhofer — Physciaceae
LICH	*Rinodina plana* H. Magn. — Physciaceae
LICH	*Rinodina pyrina* (Ach.) Arnold — Physciaceae
VASC	*Roella ciliata* L. — Campanulaceae
VASC	*Roella decurrens* L‘Hér — Campanulaceae
VASC	*Roella prostrata* E.Mey. ex A.DC. — Campanulaceae
VASC	*Roella squarrosa* P.J.Bergius — Campanulaceae
VASC	*Roella triflora* (R.D.Good) Adamson — Campanulaceae
VASC	*Roepera flexuosa* (Eckl. & Zeyh.) Beier & Thulin — Zygophyllaceae
VASC	*Rogeria bigibbosa* Engl. — Pedaliaceae
VASC	*Rogeria longiflora* (Royen) J.Gay ex DC. — Pedaliaceae
VASC	*Romulea flava* (Lam.) M.P.de Vos — Iridaceae
VASC	*Romulea hirsuta* (Steud. ex Klatt) Baker — Iridaceae
VASC	*Rotheca myricoides* (Hochst.) Steane & Mabb. — Lamiaceae
VASC	*Rotheca uncinata* (Schinz) P.P.J.Herman & Retief — Lamiaceae
VASC	*Ruellia patula* Jacq. — Acanthaceae
VASC	*Ruelliopsis damarensis* S.Moore — Acanthaceae
VASC	*Ruelliopsis setosa* (Nees) C.B.Clarke — Acanthaceae
VASC	*Rumex cordata* Poir. — Polygonaceae
VASC	*Rumex crispus* L. — Polygonaceae
VASC	*Rumex lativalvis* Meisn. — Polygonaceae
VASC	*Ruschia abbreviata* L.Bolus — Aizoaceae
VASC	*Ruschia aggregata* L.Bolus — Aizoaceae
VASC	*Ruschia atrata* L.Bolus — Aizoaceae
VASC	*Ruschia bolusiae* Schwantes — Aizoaceae
VASC	*Ruschia burtoniae* L.Bolus — Aizoaceae
VASC	*Ruschia centrocapsula* H.E.K.Hartmann & Stüber — Aizoaceae
VASC	*Ruschia crassisepala* L.Bolus — Aizoaceae
VASC	*Ruschia cyathiformis* L. Bolus — Aizoaceae
VASC	*Ruschia fredericii* (L.Bolus) L.Bolus — Aizoaceae
VASC	*Ruschia goodiae* L.Bolus — Aizoaceae
VASC	*Ruschia grisea* (L.Bolus) Schwantes — Aizoaceae
VASC	*Ruschia leucosperma* L.Bolus — Aizoaceae
VASC	*Ruschia pauciflora* L.Bolus — Aizoaceae
VASC	*Ruschia robusta* L.Bolus — Aizoaceae
VASC	*Ruschia sarmentosa* (Haw.) Schwantes — Aizoaceae
VASC	*Ruschia senaria* L.Bolus — Aizoaceae
VASC	*Ruschia spinosa* (L.) Dehn — Aizoaceae
VASC	*Ruschia stricta* L.Bolus — Aizoaceae
VASC	*Ruschia subsphaerica* L.Bolus — Aizoaceae
VASC	*Ruschia versicolor* L.Bolus — Aizoaceae
VASC	*Ruschia viridifolia* L.Bolus — Aizoaceae
VASC	*Ruschiella lunulata* (A.Berger) Klak — Aizoaceae
MAM	*Saccostomus campestris* Peters, 1846 — Nesomyidae
VASC	*Salacia luebbertii* Loes. — Celastraceae
VASC	*Salix mucronata* subsp. *capensis* (Thunb.) Immelman — Salicaceae
VASC	*Salsola aphylla* L.f. — Chenopodiaceae
VASC	*Salsola arborea* C.A.Sm. ex Aellen — Chenopodiaceae
VASC	*Salsola decussata* C.A.Sm. ex Botsch. — Chenopodiaceae
VASC	*Salsola glabrescens* Burtt Davy — Chenopodiaceae
VASC	*Salsola kali* L. — Chenopodiaceae
VASC	*Salsola rabieana* I.Verd. — Chenopodiaceae
VASC	*Salsola tuberculata* (Moq.) Fenzl — Chenopodiaceae
VASC	*Salsola tuberculatiformis* Botsch. — Chenopodiaceae
VASC	*Salsola zeyheri* (Moq.) Bunge — Chenopodiaceae
VASC	*Saltera sarcocolla* (L.) Bullock — Penaeaceae
VASC	*Salvia africana-lutea* L. — Lamiaceae
VASC	*Salvia dentata* Aiton — Lamiaceae

VASC	*Salvia gariepensis* E.Mey. ex Benth. — Lamiaceae
VASC	*Salvia lanceolata* Lam. — Lamiaceae
VASC	*Salvia verbenaca* L. — Dracaenaceae
VASC	*Sansevieria aethiopica* Thunb. — Geraniaceae
LICH	*Santessonia hereroensis* (Vain.) Follmann — Physciaceae
INSE	*Sarangesa phidyle* (Walker, 1870) — Hesperidae
VASC	*Sarcocaulon crassicaule* Rhem — Geraniaceae
VASC	*Sarcocaulon l´heritieri* (DC.) Sweet — Geraniaceae
VASC	*Sarcocaulon patersonii* (DC.) G.Don — Geraniaceae
VASC	*Sarcocaulon salmoniflorum* Moffett — Chenopodiaceae
VASC	*Sarcocornia capensis* (Moss) A.J. Scott — Chenopodiaceae
VASC	*Sarcocornia xerophila* (Tölken) A.J.Scott — Asclepiadaceae
VASC	*Sarcostemma viminale* (L.) R.Br. — Orchidaceae
VASC	*Satyrium bicorne* (L.) Thunb. — Orchidaceae
VASC	*Satyrium bracteatum* (L.f.) Thunb. — Orchidaceae
VASC	*Satyrium coriifolium* Sw. — Orchidaceae
VASC	*Satyrium erectum* Sw. — Orchidaceae
VASC	*Satyrium odorum* Sond. — Aizoaceae
INSE	*Saxicoris verrucosus* Slater, 1970 — Piesmatidae
INSE	*Scantius forsteri* (Fabricius, 1781) — Pyrrhocoridae
VASC	*Sceletium exalatum* Gerbaulet — Aizoaceae
VASC	*Sceletium tortuosum* (L.) N.E.Br. — Euphorbiaceae
INSE	*Schedorhinotermes lamanianus* (Sjöstedt, 1911) — Rhinotermitidae
VASC	*Schinziophyton rautanenii* (Schinz) Radcl.-Sm. — Poaceae
VASC	*Schismus barbatus* (Loefl. ex L.) Thell. — Poaceae
VASC	*Schizachyrium exile* (Hochst.) Pilg. — Schizaeaceae
VASC	*Schizaea pectinata* (L.) Sw. — Schizaeaceae
VASC	*Schizodium flexuosum* (L.) Lindl. — Asclepiadaceae
VASC	*Schizoglossum orbiculare* Schltr. — Asteraceae
VASC	*Schkuhria pinnata* (Lam.) Cabrera — Poaceae
VASC	*Schmidtia kalahariensis* Stent — Poaceae
VASC	*Schmidtia pappophoroides* Steud. — Cyperaceae
VASC	*Schoenoplectus roylei* (Nees) Ovcz. & Czukov. — Cyperaceae
VASC	*Schoenoplectus senegalensis* (Steud.) J.Raynal — Family
VASC	*Scirpoides dioecus* (Kunth) J.Browning — Cyperaceae
INSE	*Scythris vogelfederbergensis* Mey, 2010 — Scythrididae
VASC	*Sebaea aurea* (L.f.) Roem. & Schult. — Gentianaceae
VASC	*Sebaea exacoides* (L.) Schinz — Gentianaceae
VASC	*Sebaea grandis* (E.Mey.) Steud. — Gentianaceae
VASC	*Sebaea schlechteri* Schinz — Gentianaceae
VASC	*Securidaca longepedunculata* Fresen — Polygalaceae
VASC	*Seddera suffruticosa* (Schinz) Hallier f. — Convolvulaceae
VASC	*Seidelia firmula* (Prain) Pax & K.Hoffm. — Euphorbiaceae
VASC	*Seidelia triandra* (E.Mey.) Pax — Euphorbiaceae
VASC	*Selaginella pygmaea* (Kaulf.) Alston — Selaginellaceae
VASC	*Selago albida* Choisy — Scrophulariaceae
VASC	*Selago capituliflora* Rolfe — Scrophulariaceae
VASC	*Selago cryptadenia* Hilliard — Scrophulariaceae
VASC	*Selago dinteri* Rolfe — Scrophulariaceae
VASC	*Selago divaricata* L.f. — Scrophulariaceae
VASC	*Selago glutinosa* E.Mey. — Scrophulariaceae
VASC	*Selago glutinosa* subsp. *cylindriphylla* Hilliard — Scrophulariaceae
VASC	*Selago namaquensis* Schltr. — Scrophulariaceae
VASC	*Senecio abruptus* Thunb. — Asteraceae
VASC	*Senecio aloides* DC. — Asteraceae
VASC	*Senecio arenarius* Thunb. — Asteraceae
VASC	*Senecio bulbinifolius* DC. — Asteraceae
VASC	*Senecio cardaminifolius* DC. — Asteraceae
VASC	*Senecio cicatricosus* Sch.Bip. — Asteraceae
VASC	*Senecio cinerascens* Aiton — Asteraceae
VASC	*Senecio consanguineus* DC. — Asteraceae
VASC	*Senecio crassulaefolius* (DC.) Sch.Bip. — Asteraceae
VASC	*Senecio eenii* (S.Moore) Merxm. — Asteraceae
VASC	*Senecio engleranus* O.Hoffm. — Asteraceae
VASC	*Senecio laticipes* Bruyns — Asteraceae
VASC	*Senecio muricatus* Thunb. — Asteraceae
VASC	*Senecio niveus* (Thunb.) Willd. — Asteraceae
VASC	*Senecio paarlensis* DC. — Asteraceae
VASC	*Senecio parvifolius* DC. — Asteraceae
VASC	*Senecio pterophorus* DC. — Asteraceae
VASC	*Senecio pubigerus* L. — Asteraceae
VASC	*Senecio radicans* (L.f.) Sch.Bip. — Asteraceae
VASC	*Senecio rowleyanus* H.Jacobsen — Asteraceae
VASC	*Senecio sarcoides* C.Jeffrey — Asteraceae
VASC	*Senecio sisymbriifolius* DC. — Asteraceae
VASC	*Senecio sulcicalyx* Baker — Asteraceae
VASC	*Senecio triqueter* DC. — Asteraceae
VASC	*Senecio umbellatus* L. — Asteraceae
VASC	*Senna italica* Mill. — Fabaceae
INSE	*Sepontia misella* Stål, 1854 — Pentatomidae
VASC	*Septulina glauca* (Thunb.) Tiegh. — Loranthaceae
VASC	*Sericocoma heterochiton* Lopr. — Amaranthaceae
VASC	*Sericorema remotiflora* (Hook.f.) Loopr. — Amaranthaceae
VASC	*Sericorema sericea* (Schinz) Lopr. — Amaranthaceae
AVES	*Serinus alario* (Linnaeus, 1758) — Fringillidae
AVES	*Serinus albogularis* (A.Smith, 1833) — Fringillidae
AVES	*Serinus flaviventris* (Swainson, 1828) — Fringillidae
AVES	*Serinus mozambicus* (Müller 1776) — Fringillidae
VASC	*Seriphium plumosum* L. — Asteraceae
VASC	*Serruria brownii* Meisn. — Proteaceae
VASC	*Serruria candicans* R.Br. — Proteaceae
VASC	*Serruria decipiens* R.Br. — Proteaceae
VASC	*Serruria fasciflora* Salisb. ex Knight — Proteaceae
VASC	*Serruria glomerata* (L.) R.Br. — Proteaceae
VASC	*Serruria linearis* Salisb. ex Knight — Proteaceae
VASC	*Serruria villosa* (Lam.) R.Br. — Proteaceae
VASC	*Sesamum alatum* Thonn. — Pedaliaceae
VASC	*Sesamum capense* Burm.f. — Pedaliaceae
VASC	*Sesamum schinzianum* Asch. — Pedaliaceae
VASC	*Sesamum triphyllum* Welw. ex Ach. — Pedaliaceae
VASC	*Sesbania macowaniana* Schinz — Fabaceae
VASC	*Sesbania sesban* (L.) Merr. — Fabaceae
VASC	*Sesbania sphaerosperma* Welw. — Fabaceae
VASC	*Sesuvium sesuvioides* (Fenzl) Verdc. — Aizoaceae
VASC	*Setaria appendiculata* (Hack.) Stapf — Poaceae
VASC	*Setaria pumila* (Poir.) Roem. & Schult — Poaceae
VASC	*Setaria sphacelata* var. *sericea* (Stapf) Clayton — Poaceae
VASC	*Setaria verticillata* (L.) P.Beauv. — Poaceae
VASC	*Sida acuta* Burm.f. — Malvaceae
VASC	*Sida cordifolia* L. — Malvaceae
VASC	*Sida ovata* Forssk. — Malvaceae
INSE	*Sigara meridionalis* (Wallengren, 1875) — Corixidae
VASC	*Silene bellidioides* Sond. — Caryophyllaceae
VASC	*Silene burchellii* Otth var. *angustifolia* Sond. — Caryophyllaceae
VASC	*Silene burchellii* Otth var. *burchellii* — Caryophyllaceae
INSE	*Sinuessa subinermis* (Horváth, 1910) — Tingidae
LICH	*Siphula flavovirens* Kantvilas et al. — Icmadophilaceae
VASC	*Sisymbrium capense* Thunb. — Brassicaceae
VASC	*Sisymbrium officinale* (L.) Scop. — Brassicaceae
VASC	*Sisyndite spartea* E.Mey. ex Sond. — Zygophyllaceae
VASC	*Solanum burchellii* Dunal — Solanaceae
VASC	*Solanum capense* L. — Solanaceae
VASC	*Solanum catombelense* Peyr. — Solanaceae
VASC	*Solanum delagoense* Dunal — Solanaceae
VASC	*Solanum dinteri* Bitter — Solanaceae
VASC	*Solanum giftbergense* Dunal — Solanaceae
VASC	*Solanum lichtensteinii* Willd. — Solanaceae
VASC	*Solanum namaquense* Dammer — Solanaceae
VASC	*Solanum nigrum* L. — Solanaceae
VASC	*Solanum rigescentoides* Hutch. — Solanaceae
VASC	*Solanum seaforthianum* Andrews — Solanaceae
VASC	*Solanum supinum* Dunal — Solanaceae
VASC	*Solanum tettense* var. *renschii* (Vatke) A.E.Gonc. — Solanaceae
INSE	*Solenostedium lilligerum* Thunberg, 1783 — Scutelleridae
VASC	*Sonchus oleraceus* L. — Asteraceae
VASC	*Sonderina hispida* (Thunb.) H.Wolff — Apiaceae
VASC	*Spergularia media* (L.) C.Presl ex Griseb. — Caryophyllaceae
VASC	*Spermacoce senensis* (Klotzsch) Hiern — Rubiaceae
VASC	*Sphedamnocarpus pruriens* (A.Juss.) Szyszyl. — Malpighiaceae
VASC	*Sphedamnocarpus pruriens* (A.Juss.) Szyszyl. subsp. *pruriens* — Malpighiaceae
INSE	*Sphedanolestes nanus* Stål, 1855 — Reduviidae
INSE	*Spialia colotes transvaaliae* (Trimen & Bowker, 1889) — Hesperidae
INSE	*Spialia delagoae* (Trimen, 1898) — Hesperidae
INSE	*Spialia diomus* (Hopffer, 1855) — Hesperidae
INSE	*Spialia diomus ferox* Wallengren, 1863 — Hesperiidae
INSE	*Spialia mafa mafa* Trimen, 1870 — Hesperiidae

INSE	*Spialia spio* (Linnaeus, 1767) — Hesperidae
INSE	*Spilostethus macilentus* (Stål, 1874) — Lygaeidae
INSE	*Spilostethus pandurus elegans* (Wolff, 1802) — Lygaeidae
INSE	*Spilostethus trilineatus* Dallas, 1852 — Lygaeidae
VASC	*Spiloxene aquatica* (L.f.) Fourc. — Hypoxidaceae
VASC	*Spiloxene capensis* (L.) Garside — Hypoxidaceae
VASC	*Spiloxene ovata* (L.f.) Garside — Hypoxidaceae
VASC	*Spiloxene schlechteri* (Bolus) Garside — Hypoxidaceae
DIPL	*Spirostreptus heros* Porat, 1872 — Spirostreptidae
INSE	*Spodoptera exigua* (Hübner, 1808) — Noctuidae
VASC	*Sporobolus africanus* (Poir.) Robyns & Tournay — Poaceae
VASC	*Sporobolus coromandelianus* (Retz.) Kunth — Poaceae
VASC	*Sporobolus festivus* Hochst. ex A.Rich. — Poaceae
VASC	*Sporobolus fimbriatus* (Trin.) Nees — Poaceae
VASC	*Sporobolus ioclados* (Trin.) Nees — Poaceae
VASC	*Sporobolus nebulosus* Hack. — Poaceae
VASC	*Sporobolus nervosus* Hochst. — Poaceae
VASC	*Sporobolus panicoides* A.Rich. — Poaceae
AVES	*Sporopipes squamifrons* (A.Smith, 1836) — Ploceidae
AVES	*Spreo bicolor* (J.F.Gmelin, 1789) — Sturnidae
VASC	*Staavia radiata* (L.) Dahl — Bruniaceae
VASC	*Staberoha cernua* (L.f.) T.Durand & Schinz — Restionaceae
VASC	*Staberoha distachyos* (Rottb.) Kunth — Restionaceae
VASC	*Stachys rugosa* Aiton — Lamiaceae
VASC	*Stapelia hirsuta* var. *gariepensis* (Pillans) Bruyns — Apocynaceae
INSE	*Staudingeria mimeugraphella* Balinsky, 1989 — Pyralidae
LICH	*Staurothele dendritica* V. Wirth — Verrucariaceae
VASC	*Steganotaenia araliacea* Hochst. — Apiaceae
VASC	*Steirodiscus gamolepis* Bolus ex Schltr. — Asteraceae
INSE	*Stenophthalmicus tenuatus* (Hesse, 1925) — Geocoridae
INSE	*Stenozygum sanguineiventris* Hesse, 1925 — Pentatomidae
INSE	*Stenozygum senegalense* (Fabricius, 1803) — Pentatomidae
AVES	*Stigmatopelia senegalensis* (Linnaeus, 1766) — Columbidae
VASC	*Stilbe ericoides* (L.) L. — Stilbaceae
VASC	*Stipa capensis* Thunb. — Poaceae
VASC	*Stipagrostis amabilis* (Schweick.) De Winter — Poaceae
VASC	*Stipagrostis anomala* De Winter — Poaceae
VASC	*Stipagrostis brevifolia* (Nees) De Winter — Poaceae
VASC	*Stipagrostis ciliata* (Desf.) De Winter — Poaceae
VASC	*Stipagrostis ciliata* var. *capensis* (Trin. & Rupr.) De Winter — Poaceae
VASC	*Stipagrostis dregeana* Nees — Poaceae
VASC	*Stipagrostis geminifolia* Nees — Poaceae
VASC	*Stipagrostis gonatostachys* (Pilg.) De Winter — Poaceae
VASC	*Stipagrostis hirtigluma* (Trin. & Rupr.) De Winter — Poaceae
VASC	*Stipagrostis hirtigluma* (Trin. & Rupr.) De Winter subsp. *hirtigluma* — Poaceae
VASC	*Stipagrostis hochstetteriana* (Beck ex Hack.) De Winter — Poaceae
VASC	*Stipagrostis lutescens* (Nees) De Winter — Poaceae
VASC	*Stipagrostis namaquensis* (Nees) De Winter — Poaceae
VASC	*Stipagrostis namibensis* De Winter — Poaceae
VASC	*Stipagrostis obtusa* (Delile) Nees — Poaceae
VASC	*Stipagrostis schaeferi* (Mez) De Winter — Poaceae
VASC	*Stipagrostis subacaulis* (Nees) De Winter — Poaceae
VASC	*Stipagrostis uniplumis* (Licht.) De Winter — Poaceae
VASC	*Stipagrostis uniplumis* (Licht.) De Winter var. *uniplumis* — Poaceae
VASC	*Stipagrostis zeyheri* (Nees) De Winter — Poaceae
VASC	*Stipagrostis zeyheri* (Nees) De Winter subsp. *zeyheri* — Poaceae
INSE	*Stizus* Latreille, 1802 — Crabronidae
VASC	*Stoebe capitata* P.J.Bergius — Asteraceae
VASC	*Stoebe cyathuloides* Schltr. — Asteraceae
VASC	*Stoebe fusca* (L.) Thunb. — Asteraceae
VASC	*Stoebe gomphrenoides* (Lam.) P.J.Bergius — Asteraceae
VASC	*Stoebe leucocephala* DC. — Asteraceae
VASC	*Stoeberia beetzii* (Dinter) Dinter & Schwantes — Aizoaceae
VASC	*Stoeberia frutescens* (L.Bolus) Van Jaarsv. — Aizoaceae
VASC	*Stoeberia gigas* (Dinter) Dinter & Schwantes — Aizoaceae
VASC	*Stoeberia utilis* (L.Bolus) Van Jaarsv. — Aizoaceae
AVES	*Streptopelia capicola* (Sundevall, 1857) — Columbidae
VASC	*Striga asiatica* (L.) Kuntze — Orobanchaceae
VASC	*Striga bilabiata* (Thunb.) Kuntze — Orobanchaceae
VASC	*Striga gesnerioides* (Willd.) Vatke ex Engl. — Orobanchaceae
AVES	*Struthio camelus* Linnaeus, 1758 — Struthionidae
VASC	*Struthiola ciliata* (L.) Lam. — Thymelaeaceae
VASC	*Struthiola dodecandra* (L.) Druce — Thymelaeaceae
VASC	*Struthiola leptantha* Bolus — Thymelaeaceae
VASC	*Strychnos cocculoides* Baker — Strychnaceae
VASC	*Strychnos pungens* Soler. — Strychnaceae
INSE	*Stygionympha vigilans* Trimen, 1887 — Satyridae
INSE	*Stygnocorisella linnavuorii* Scudder, 1969 — Rhyparochromidae
VASC	*Stylapterus fruticulosus* (L.f.) A.Juss — Penaeaceae
VASC	*Stylosanthes fruticosa* (Retz.) Alston — Fabaceae
VASC	*Suaeda fruticosa* (L.) Forssk. — Chenopodiaceae
VASC	*Suaeda plumosa* Aellen — Chenopodiaceae
VASC	*Suessenguthiella scleranthoides* (Sond.) Friedrich — Molluginaceae
INSE	*Suffenus fusconervosus* (Motschulky, 1863) — Rhyparochromidae
MAM	*Suricata suricatta* (Schreber, 1776) — Herpestidae
VASC	*Sutera foetida* Roth — Scrophulariaceae
VASC	*Sutera patriotica* Hiern — Scrophulariaceae
VASC	*Sutherlandia frutescens* (L.) R.Br. — Fabaceae
VASC	*Sutherlandia microphylla* Burch. ex DC. — Fabaceae
MAM	*Sylvicapra grimmia* (Linnaeus, 1758) — Bovidae
AVES	*Sylvietta rufescens* (Vieillot, 1817) — Sylviidae
INSE	*Sympetrum fonscolombii* (Selys, 1840) — Libellulidae
VASC	*Syncarpha speciosissima* (L.) B.Nord — Asteraceae
VASC	*Syncarpha vestita* (L.) B.Nord. — Asteraceae
INSE	*Syncordulia gracilis* (Burmeister, 1839) — Corduliidae
INSE	*Syncordulia legator* Dijkstra et al. 2007 — Corduliidae
INSE	*Syncordulia serendipator* Dijkstra et al. 2007 — Corduliidae
INSE	*Syncordulia venator* (Barnard, 1933) — Corduliidae
VASC	*Tagetes minuta* L. — Asteraceae
VASC	*Talinum arnotii* Hook.f. — Portulacaceae
VASC	*Talinum caffrum* (Thunb.) Eckl. & Zeyh. — Portulacaceae
VASC	*Talinum crispatulum* Dinter ex Poelln. — Portulacaceae
VASC	*Talinum tenuissimum* Dinter — Portulacaceae
VASC	*Tapinanthus oleifolius* (J.C.Wendl.) Danser — Loranthaceae
VASC	*Tarchonanthus camphoratus* L. — Asteraceae
INSE	*Tarsocera cassus cassus* (Linnaeus, 1764) — Nymphalidae
INSE	*Tarsocera imitator imitator* Vári, 1971 — Nymphalidae
INSE	*Tarucus thespis* (Linnaeus, 1764) — Lycaenidae
INSE	*Tarucus sybaris linearis* (Aurivillius, 1924) — Lycaenidae
VASC	*Tavaresia barklyi* (Dyer) N.E.Br. — Asclepiadaceae
AVES	*Tchagra australis* (A.Smith, 1836) — Malaconotidae
VASC	*Teedia lucida* (Sol.) Rudolphi — Scrophulariaceae
AVES	*Telophorus zeylonus* (Linnaeus, 1766) — Malaconotidae
LICH	*Teloschistes capensis* (L.f.) Müll. Arg. — Teloschistaceae
LICH	*Teloschistes chrysophthalmus* (L.) Beltram. — Teloschistaceae
VASC	*Tenicroa filifolia* (Jacq.) Oberm. — Hyacinthaceae
INSE	*Tenosius proletarius* (Schaum, 1853) — Alydidae
VASC	*Tephrosia burchellii* Burtt Davy — Fabaceae
VASC	*Tephrosia cephalantha* Welw. ex Baker — Fabaceae
VASC	*Tephrosia dregeana* E.Mey. — Fabaceae
VASC	*Tephrosia lupinifolia* DC. — Fabaceae
VASC	*Tephrosia purpurea* (L.) Pers. — Fabaceae
VASC	*Tephrosia purpurea* (DC.) Brummitt var. *leptostachya* — Fabaceae
VASC	*Tephrosia purpurea* var. pubescens Baker — Fabaceae
INSE	*Teracrius namaquensis* (Stål, 1858) — Pachygronthidae
AVES	*Terathopius ecaudatus* (Daudin, 1800) — Accipitridae
VASC	*Terminalia sericea* Burch. ex DC. — Combretaceae
VASC	*Tetragonia calycina* Fenzl — Aizoaceae
VASC	*Tetragonia decumbens* Mill. — Aizoaceae
VASC	*Tetragonia echinata* Aiton — Aizoaceae
VASC	*Tetragonia fruticosa* L. — Aizoaceae
VASC	*Tetragonia microptera* Fenzl — Aizoaceae
VASC	*Tetragonia reduplicata* Welw. ex Oliv. — Aizoaceae
VASC	*Tetragonia schenckii* (Schinz) Engl. — Aizoaceae
VASC	*Tetragonia verrucosa* Fenzl — Aizoaceae
VASC	*Tetraria bromoides* (Lam.) Pfeiff. — Cyperaceae
VASC	*Tetraria compar* (L.) Lestib. — Cyperaceae
VASC	*Tetraria crinifolia* (Nees) C.B.Clarke — Cyperaceae
VASC	*Tetraria cuspidata* (Rottb.) C.B.Clarke — Cyperaceae
VASC	*Tetraria flexuosa* (Thunb.) C.B.Clarke — Cyperaceae
VASC	*Tetraria microstachys* (Vahl) Pfeiff. — Cyperaceae

VASC	*Tetraria ustulata* (L.) C.B.Clarke — Cyperaceae
VASC	*Thamnochortus bachmanii* Mast. — Restionaceae
VASC	*Thamnochortus fruticosus* P.J.Bergius — Restionaceae
VASC	*Thamnochortus insignis* Mast. — Restionaceae
VASC	*Thamnochortus lucens* (Poir.) H.P.Linder — Restionaceae
VASC	*Thamnochortus punctatus* Pillans — Restionaceae
INSE	*Thaumastella namaquensis* Schaefer & Wilcox, 1971 — Thaumastellidae
VASC	*Themeda triandra* Forssk. — Poaceae
VASC	*Thereianthus bracteolatus* (Lam.) G.J.Lewis — Iridaceae
VASC	*Thesium capitatum* L. — Santalaceae
VASC	*Thesium capitellatum* A.DC. — Santalaceae
VASC	*Thesium capituliflorum* Sond. — Santalaceae
VASC	*Thesium elatius* Sond. — Santalaceae
VASC	*Thesium euphorbioides* L. — Santalaceae
VASC	*Thesium juncifolium* DC. — Santalaceae
VASC	*Thesium lacinulatum* A.W.Hill — Santalaceae
VASC	*Thesium lineatum* L.f. — Santalaceae
VASC	*Thesium megalocarpum* A.W.Hill — Santalaceae
VASC	*Thesium pycnanthum* Schltr. — Santalaceae
VASC	*Thesium spicatum* L. — Santalaceae
VASC	*Thesium spinosum* L.f. — Santalaceae
VASC	*Thesium strictum* P.J.Bergius — Santalaceae
VASC	*Thesium virgatum* Lam. — Santalaceae
VASC	*Thesium viridifolium* Levyns — Santalaceae
VASC	*Thesium zeyheri* A.DC. — Santalaceae
INSE	*Tholymis tillarga* (Fabricius, 1798) — Libellulidae
VASC	*Thunbergia aurea* N.E.Br. — Acanthaceae
LICH	*Thyrea plicatissima* (Nyl.) Zahlbr. — Lichinaceae
INSE	*Thyretis caffra* Wallengren, 1863 — Arctiidae
AVES	*Tockus erythrorhynchus* (Temminck, 1823) — Bucerotidae
AVES	*Tockus leucomelas* (Lichtenstein, 1842) — Bucerotidae
AVES	*Tockus monteiri* (Hartlaub, 1865) — Bucerotidae
AVES	*Tockus nasutus* Linnaeus, 1766 — Bucerotidae
LICH	*Toninia australis* Timdal — Ramalinaceae
LICH	*Toninia lutosa* (Ach.) Timdal — Ramalinaceae
LICH	*Toninia* aff. *ruginosa* (Tuck.) Herre — Ramalinaceae
LICH	*Toninia ruginosa* subsp. *pacifica* Timdal — Ramalinaceae
LICH	*Toninia ruginosa* subsp. *ruginosa* (Tuck.) Herre — Ramalinaceae
VASC	*Trachyandra arvensis* (Schinz) Oberm. — Asphodelaceae
VASC	*Trachyandra bulbinifolia* (Dinter) Oberm. — Asphodelaceae
VASC	*Trachyandra chlamydophylla* (Baker) Oberm. — Asphodelaceae
VASC	*Trachyandra ciliata* (L.f.) Kunth — Asphodelaceae
VASC	*Trachyandra divaricata* (Jacq.) Kunth — Asphodelaceae
VASC	*Trachyandra falcata* (L.f.) Kunth — Asphodelaceae
VASC	*Trachyandra filiformis* (Aiton) Oberm. — Asphodelaceae
VASC	*Trachyandra flexifolia* (L.f.) Kunth — Asphodelaceae
VASC	*Trachyandra hirsutiflora* (Adamson) Oberm. — Asphodelaceae
VASC	*Trachyandra involucrata* (Baker) Oberm. — Asphodelaceae
VASC	*Trachyandra laxa* (N.E.Br.) Oberm. — Asphodelaceae
VASC	*Trachyandra muricata* (L.f.) Kunth — Asphodelaceae
VASC	*Trachyandra revoluta* (L.) Kunth — Asphodelaceae
VASC	*Trachyandra saltii* (Baker) Oberm. var. *saltii* — Asphodelaceae
VASC	*Trachyandra tortilis* (Baker) Oberm. — Asphodelaceae
REPT	*Trachylepis capensis* (Gray, 1831) — Scincidae
MAM	*Tragelaphus strepsiceros* (Pallas, 1766) — Bovidae
VASC	*Tragia dioica* Sond. — Euphorbiaceae
VASC	*Tragia lancifolia* Dinter ex Pax & K.Hoffmann — Euphorbiaceae
VASC	*Tragia okanyua* Pax — Euphorbiaceae
VASC	*Tragus berteronianus* Schult. — Poaceae
VASC	*Tragus racemosus* (L.) All. — Poaceae
INSE	*Tramea basilaris* (Palisot de Beauvois, 1807) — Libellulidae
INSE	*Tramea limbata* (Desjardins, 1832) — Libellulidae
VASC	*Trianoptiles stipitata* Levyns — Cyperaceae
VASC	*Trianthema parvifolia* E.Mey. ex Sond. — Aizoaceae
VASC	*Trianthema triquetra* Rottler ex Willd. — Aizoaceae
VASC	*Tribolium hispidum* (Thunb.) Desv. — Poaceae
VASC	*Tribolium uniolae* (L.f.) Renvoize — Poaceae
VASC	*Tribolium utriculosum* (Nees) Renvoize — Poaceae
VASC	*Tribulus cristatus* C.Presl — Zygophyllaceae
VASC	*Tribulus pterophorus* C.Presl — Zygophyllaceae
VASC	*Tribulus terrestris* L. — Zygophyllaceae
VASC	*Tribulus zeyheri* Sond. — Zygophyllaceae
VASC	*Trichocephalus stipularis* (L.) Brongn. — Rhamnaceae
INSE	*Trichodes aulicus* Klug, 1842 — Cleridae
VASC	*Trichodesma africanum* (L.) Lehm. — Boraginaceae
VASC	*Trichogyne lerouxiae* Beyers — Asteraceae
VASC	*Trichogyne polycnemoides* (Fenzl) Anderb. — Asteraceae
INSE	*Tricholabiodes* Radoszkowski, 1885 — Mutillidae
AVES	*Tricholaema leucomelas* (Boddaert, 1783) — Ramphastidae
VASC	*Tricholaena monachne* (Trin.) Stapf & C.E.Hubb. — Poaceae
VASC	*Trichoneura grandiglumis* (Nees) Ekman — Poaceae
INSE	*Trichophaga cuspidata* Gozmány, 1967 — Tineidae
VASC	*Tricliceras schinzii* var. *juttae* (Dinter & Urb.) R.Fern. — Turneraceae
VASC	*Triglochin bulbosa* L. — Juncaceae
GAST	*Trigonephrus* Pilsbry, 1905 — Dorcasiidae
INSE	*Trinervitermes* Holmgren, 1912 — Termitidae
VASC	*Tripteris aghillana* DC. — Asteraceae
VASC	*Tripteris amplectens* Harv. — Asteraceae
VASC	*Tripteris clandestina* Less. — Asteraceae
VASC	*Tripteris dentata* (Burm.f.) Harv. — Asteraceae
VASC	*Tripteris hyoseroides* DC. — Asteraceae
VASC	*Tripteris microcarpa* Harv. — Asteraceae
VASC	*Tripteris microcarpa* Harv. subsp. *microcarpa* — Asteraceae
VASC	*Tripteris nervosa* Hutch. — Asteraceae
VASC	*Tripteris oppositifolia* (Aiton) B.Nord. — Asteraceae
VASC	*Tripteris sinuata* DC. — Asteraceae
VASC	*Tripteris sinuata* DC. var. *sinuata* — Asteraceae
VASC	*Triraphis purpurea* Hack. — Poaceae
VASC	*Triraphis ramosissima* Hack. — Poaceae
VASC	*Triraphis schinzii* Hack. — Poaceae
VASC	*Tristachya superba* (De Not.) Schweinf. & Asch. — Poaceae
INSE	*Trithemis aconita* Lieftinck, 1969 — Libellulidae
INSE	*Trithemis aequalis* Lieftinck, 1969 — Libellulidae
INSE	*Trithemis annulata* (Palisot de Beauvois, 1807) — Libellulidae
INSE	*Trithemis arteriosa* (Burmeister, 1839) — Libellulidae
INSE	*Trithemis brydeni* Pinhey, 1970 — Libellulidae
INSE	*Trithemis donaldsoni* (Calvert, 1899) — Libellulidae
INSE	*Trithemis dorsalis* (Rambur, 1842) — Libellulidae
INSE	*Trithemis furva* Karsch, 1899 — Libellulidae
INSE	*Trithemis hecate* Ris, 1912 — Libellulidae
INSE	*Trithemis kirbyi ardens* (Gerstäcker, 1891) — Libellulidae
INSE	*Trithemis monardi* Ris, 1931 — Libellulidae
INSE	*Trithemis morrisoni* Damm & Haydrs, 2009 — Libellulidae
INSE	*Trithemis palustris* Damm & Hadrys, 2009 — Libellulidae
INSE	*Trithemis pluvialis* Förster, 1906 — Libellulidae
INSE	*Trithemis stictica* (Burmeister, 1839) — Libellulidae
INSE	*Trithemis werneri* Ris, 1912 — Libellulidae
INSE	*Trithetrum navasi* (Lacroix, 1921) — Libellulidae
VASC	*Tritoniopsis dodii* (G.J.Lewis) G.J.Lewis — Iridaceae
VASC	*Tritoniopsis triticea* (Burm.f.) Goldblatt — Iridaceae
VASC	*Tromotriche longipes* (C.A.Lückh.) Bruyns — Apocynaceae
VASC	*Tulbaghia alliacea* L.f. — Alliaceae
VASC	*Tulbaghia dregeana* Kunth — Alliaceae
INSE	*Tupalus fasciatus* (Dallas, 1852) — Alydidae
AVES	*Turnix sylvaticus* (Desfontaines, 1789) — Turnicidae
AVES	*Turtur chalcospilos* (Wagler, 1827) — Columbidae
INSE	*Tuxentius melaena melaena* (Trimen, 1887) — Lycaenidae
INSE	*Tychius* Germar, 1817 — Curculionidae
VASC	*Tylecodon buchholzianus* (Schuldt & P.Stephan) Tölken — Crassulaceae
VASC	*Tylecodon occultans* (Tölken) Tölken — Crassulaceae
VASC	*Tylecodon paniculatus* (L.f.) Tölken — Crassulaceae
VASC	*Tylecodon pearsonii* (Schönland) Tölken — Crassulaceae
VASC	*Tylecodon pygmaeus* (W.F.Barker) Tölken — Crassulaceae
VASC	*Tylecodon reticulatus* (L.f.) Tölken subsp. *reticulatus* — Crassulaceae
VASC	*Tylecodon rubrovenosus* (Dinter) Tölken — Crassulaceae
VASC	*Tylecodon schaeferianus* (Dinter) Tölken — Crassulaceae
VASC	*Tylecodon tenuis* (Tölken) Bruyns — Crassulaceae
VASC	*Tylecodon wallichii* (Harv.) Tölken — Crassulaceae
VASC	*Tylosema esculentum* (Burch.) A.Schreib. — Fabaceae
AVES	*Tyto alba* (Scopoli, 1769) — Tytonidae
AVES	*Upupa epops africana* Bechstein, 1811 — Upupidae
AVES	*Uraeginthus angolensis* (Linnaeus, 1758) — Estrildidae
AVES	*Uraeginthus granatinus* (Linnaeus, 1766) — Estrildidae
INSE	*Urentius euonymus* Distant, 1909 — Tingidae

INSE	*Uresiphita polygonalis* (Denis & Schiffermüller, 1775) — Crambidae
VASC	*Urochloa brachyura* (Hack.) Stapf — Poaceae
VASC	*Urochloa panicoides* P.Beauv. — Poaceae
VASC	*Urochloa trichopus* (Hochst.) Stapf — Poaceae
AVES	*Urocolius indicus* Latham, 1790 — Coliidae
INSE	*Urothemis assignata* (Selys, 1872) — Libellulidae
INSE	*Urothemis edwardsii* (Selys, 1849) — Libellulidae
VASC	*Ursinia anthemoides* (L.) Poir. — Asteraceae
VASC	*Ursinia anthemoides* (L) Poir. subsp. *anthemoides* — Asteraceae
VASC	*Ursinia cakilefolia* DC. — Asteraceae
VASC	*Ursinia chrysanthemoides* (Less.) Harv. — Asteraceae
VASC	*Ursinia nana* DC. — Asteraceae
VASC	*Ursinia nana* DC. subsp. *nana* — Asteraceae
VASC	*Ursinia nudicaulis* (Thunb.) N.E.Br. — Asteraceae
VASC	*Ursinia paleacea* (L.) Moench — Asteraceae
VASC	*Ursinia tenuifolia* (L.) Poir. — Asteraceae
INSE	*Utetheisa pulchella* (Linnaeus, 1758) — Arctiidae
VASC	*Utricularia bisquamata* Schrank — Lentibulariaceae
VASC	*Vahlia capensis* (L.f.) Thunb. — Vahliaceae
AVES	*Vanellus coronatus* (Boddaert, 1783) — Charadriidae
INSE	*Vanessa cardui* (Linnaeus, 1758) — Nymphalidae
VASC	*Vangueria infausta* Burch. subsp. *infausta* — Rubiaceae
VASC	*Vanzijlia annulata* (A.Berger) L.Bolus — Aizoaceae
VASC	*Vellereophyton dealbatum* (Thunb.) Hilliard & B.L.Burtt — Asteraceae
VASC	*Vernonia bainesii* Oliv. & Hiern — Asteraceae
VASC	*Vernonia fastigiata* Oliv. & Hiern — Asteraceae
VASC	*Vernonia glabra* (Steetz) Vatke — Asteraceae
VASC	*Vernonia glabra* (Steetz) Vatke var. *glabra* — Asteraceae
VASC	*Vernonia poskeana* subsp. *botswanica* G.V.Pope — Asteraceae
LICH	*Verrucaria compacta agg.* (A. Massal.) Jatta — Verrucariaceae
INSE	*Veterna imitatrix* Hesse, 1925 — Pentatomidae
INSE	*Veterna pugionata* (Stål, 1858) — Pentatomidae
AVES	*Vidua regia* (Linnaeus, 1766) — Viduidae
VASC	*Vigna lobatifolia* Baker — Fabaceae
VASC	*Vigna unguiculata* (L.) Walp. — Fabaceae
VASC	*Vigna unguiculata* subsp. *stenophylla* (Harv.) Maréchal et al. — Fabaceae
VASC	*Viscum capense* L.f. — Viscaceae
VASC	*Viscum rotundifolium* L.f. — Viscaceae
MAM	*Vulpes chama* (A.Smith, 1833) — Canidae
VASC	*Wachendorfia multiflora* (Klatt) J.C.Manning & Goldblatt — Haemodoraceae
VASC	*Wachendorfia paniculata* Burm. — Haemodoraceae
VASC	*Wahlenbergia androsacea* A.DC. — Campanulaceae
VASC	*Wahlenbergia capensis* (L.) A.DC. — Campanulaceae
VASC	*Wahlenbergia divergens* A.DC. — Campanulaceae
VASC	*Wahlenbergia longifolia* (A.DC.) Lammers — Campanulaceae
VASC	*Wahlenbergia namaquana* Sond. — Campanulaceae
VASC	*Wahlenbergia oxyphylla* A.DC. — Campanulaceae
VASC	*Wahlenbergia patula* A.DC. — Campanulaceae
VASC	*Wahlenbergia prostrata* A.DC. — Campanulaceae
VASC	*Wahlenbergia ramosissima* subsp. *lateralis* (Brehmer) Thulin — Campanulaceae
VASC	*Wahlenbergia ramulosa* E.Mey. — Campanulaceae
VASC	*Wahlenbergia schlechteri* Brehmer — Campanulaceae
VASC	*Wahlenbergia sessiliflora* Brehmer — Campanulaceae
VASC	*Wahlenbergia tenuis* A.DC. — Campanulaceae
VASC	*Wahlenbergia thunbergiana* (H.Buek) Lammers — Campanulaceae
INSE	*Wainia* Tkalců,1980 — Megachilidae
VASC	*Walleria nutans* J.Kirk — Tecophilaeaceae
VASC	*Waltheria indica* L. — Sterculiaceae
VASC	*Watsonia coccinea* Herb. ex Baker — Iridaceae
VASC	*Watsonia meriana* (L.) Mill. — Iridaceae
VASC	*Watsonia tabularis* J.W.Mathews & L.Bolus — Iridaceae
VASC	*Wellstedia dinteri* Pilg. — Boraginaceae
VASC	*Wiborgia fusca* Thunb. — Fabaceae
VASC	*Wiborgia incurvata* E.Mey — Fabaceae
VASC	*Wiborgia monoptera* E.Mey. — Fabaceae
VASC	*Willdenowia arescens* Kunth — Restionaceae
VASC	*Willdenowia incurvata* (Thunb.) H.P.Linder — Restionaceae
VASC	*Willkommia newtonii* Hack. — Poaceae
VASC	*Willkommia sarmentosa* Hack. — Poaceae
VASC	*Wimmerella secunda* (L.f.) L.Serra et al. — Lobeliaceae
VASC	*Wurmbea inusta* (Baker) B.Nord. — Colchicaceae
VASC	*Wurmbea monopetala* (L.f.) B.Nord. — Colchicaceae
VASC	*Wurmbea punctata* (L.) J.C.Manning & Vinn. — Colchicaceae
VASC	*Wurmbea recurva* B.Nord — Colchicaceae
VASC	*Wurmbea spicata* (Burm.f.) T.Durand & Schinz — Colchicaceae
LICH	*Xanthomaculina hottentotta* (Ach.) Hale — Parmeliaceae
LICH	*Xanthoparmelia amphixanthoides* (J. Steiner & Zahlbr.) Hale — Parmeliaceae
LICH	*Xanthoparmelia arrecta* (Essl.) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia austroafricana* (Stirt.) Hale — Parmeliaceae
LICH	*Xanthoparmelia crassilobata* Hale — Parmeliaceae
LICH	*Xanthoparmelia dregeana* (Hampe) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia epigaea* Hale — Parmeliaceae
LICH	*Xanthoparmelia equalis* Hale — Parmeliaceae
LICH	*Xanthoparmelia evernica* Hale — Parmeliaceae
LICH	*Xanthoparmelia follmanni* (J.C. Krug) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia hottentotta* (Ach.) A. Thell et al. — Parmeliaceae
LICH	*Xanthoparmelia hueana* (Gyeln.) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia hyporhytida* (Hale) Hale — Parmeliaceae
LICH	*Xanthoparmelia* aff. *imitatrix* (Taylor) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia incomposita* (Essl.) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia lapidula* (Essl.) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia leonora* (Spreng. ex A. Massal.) Hale — Parmeliaceae
LICH	*Xanthoparmelia namibiensis* (Elix & T.H.Nash) O.Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia prolata* (Hale) Elix — Parmeliaceae
LICH	*Xanthoparmelia serusiauxii* Hale — Parmeliaceae
LICH	*Xanthoparmelia simulans* Hale — Parmeliaceae
LICH	*Xanthoparmelia tentaculina* (Essl.) O. Blanco et al. — Parmeliaceae
LICH	*Xanthoparmelia terricola* Hale, T.H. Nash & Elix — Parmeliaceae
LICH	*Xanthoparmelia walteri* M.D.E. Knox — Parmeliaceae
LICH	*Xanthoria alexanderbaai* S.Y. Kondr. & Kärnefelt — Teloschistaceae
LICH	*Xanthoria bonae-spei* S.Y. Kondr. & Kärnefelt — Teloschistaceae
LICH	*Xanthoria dissectula* S.Y. Kondr. & Kärnefelt — Teloschistaceae
LICH	*Xanthoria karrooensis* S.Y. Kondr. & Kärnefelt — Teloschistaceae
LICH	*Xanthoria parietina* (L.) Beltr. — Teloschistaceae
LICH	*Xanthoria turbinata* Vain. — Teloschistaceae
VASC	*Xenostegia tridentata* subsp. *angustifolia* (Jacq.) Lejoly & Lisowski — Convolvulaceae
VASC	*Xerocladia viridiramis* (Burch.) Taub. — Fabaceae
VASC	*Xerophyta humilis* (Baker) T.Durand & Schinz — Velloziaceae
MAM	*Xerus inauris* (Zimmermann, 1780) — Sciuridae
VASC	*Ximenia americana* L. — Olacaceae
VASC	*Ximenia caffra* Sond. — Olacaceae
VASC	*Zaluzianskya affinis* Hilliard — Scrophulariaceae
VASC	*Zaluzianskya benthamiana* Walp. — Scrophulariaceae
VASC	*Zaluzianskya peduncularis* (Benth.) Walp. — Scrophulariaceae
VASC	*Zaluzianskya villosa* F.W.Schmidt — Scrophulariaceae
VASC	*Zea mays* L. — Poaceae
VASC	*Zehneria marlothii* (Cogn.) R.Fern. & A.Fern. — Cucurbitaceae
INSE	*Zintha hintza krooni* (Dickson, 1973) — Lycaenidae
INSE	*Zizeeria knysna* (Trimen, 1862) — Lycaenidae
VASC	*Ziziphus mucronata* Willd. — Rhamnaceae
VASC	*Ziziphus mucronata* Willd. subsp. *mucronata* — Rhamnaceae
INSE	*Zizula hylax* (Fabricius, 1775) — Lycaenidae
VASC	*Zornia glochidiata* DC. — Fabaceae
VASC	*Zornia milneana* Mohlenbr. — Fabaceae
INSE	*Zulubius maculatus* (Thunberg, 1822) — Alydidae
LICH	*Zwackhiomyces namibensis* Diederich & M.Schultz — Xanthopyreniaceae

INSE	*Zygonoides fuelleborni* (Grünberg, 1902) — Libellulidae
INSE	*Zygonyx natalensis* (Martin, 1900) — Libellulidae
INSE	*Zygonyx torridus* (Kirby, 1889) — Libellulidae
VASC	*Zygophyllum clavatum* Schltr. & Diels — Zygophyllaceae
VASC	*Zygophyllum cordifolium* L.f. — Zygophyllaceae
VASC	*Zygophyllum cylindrifolium* Shinz — Zygophyllaceae
VASC	*Zygophyllum decumbens* Delile — Zygophyllaceae
VASC	*Zygophyllum dregeanum* Sond. — Zygophyllaceae
VASC	*Zygophyllum foetidum* Schrad. & J.C. Wendl. — Zygophyllaceae
VASC	*Zygophyllum leptopetalum* E.Mey. ex Sond. — Zygophyllaceae
VASC	*Zygophyllum morgsana* L. — Zygophyllaceae
VASC	*Zygophyllum prismatocarpum* E.Mey. ex Sond. — Zygophyllaceae
VASC	*Zygophyllum pubescens* Schinz — Zygophyllaceae
VASC	*Zygophyllum retrofractum* Thunb. — Zygophyllaceae
VASC	*Zygophyllum rigidum* Schinz — Zygophyllaceae
VASC	*Zygophyllum sessilifolium* L. — Zygophyllaceae
VASC	*Zygophyllum simplex* L. — Zygophyllaceae
VASC	*Zygophyllum spinosum* L. — Zygophyllaceae
VASC	*Zygophyllum tenue* P.E.Glover — Zygophyllaceae
VASC	*Zygophyllum teretifolium* Schltr. — Zygophyllaceae

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BIOTA transect and the Biodiversity Observatories in southern Africa.

Boundaries
- International Boundary
- Provincial Border

Hydrography
- River
- Periodical River
- Salt Pan
- Lake
- Wetland

Contour Levels
- up to 300 m
- up to 600 m
- up to 900 m
- up to 1200 m
- up to 1500 m
- up to 1800 m
- more than 1800 m

Communications
- Motorway
- Road
- Railway

Populated Places
- ○ City
- ◉ Provincial Capital
- ● Capital

- Transect
- ☐ S32 Elandsberg BIOTA Observatory

Uwe Ulrich Jäschke & Karen Langner • HTW - University of Applied Sciences Dresden

Number, name and respective biome of the BIOTA Biodiversity Observatories.
Page number refers to the description of the Observatory in Volume I.

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Biodiversity is important for sustaining life on Earth yet it is threatened globally. The BIOTA Southern Africa project analysed the causes, trends, and processes of change in biodiversity in Namibia and western South Africa over nearly a full decade, from 2001 until 2010. This book, which is comprised of three volumes, offers a summary of the results from the many and diverse subprojects during this first period of long-term observation and related research, at both local and regional scales, and with a focus on sustainable land management options for the region.

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