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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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Article IV.1

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

Part IV

IV.1 Causes and perspectives of land-cover change through expanding cultivation in Kavango

Woodland Savanna

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

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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

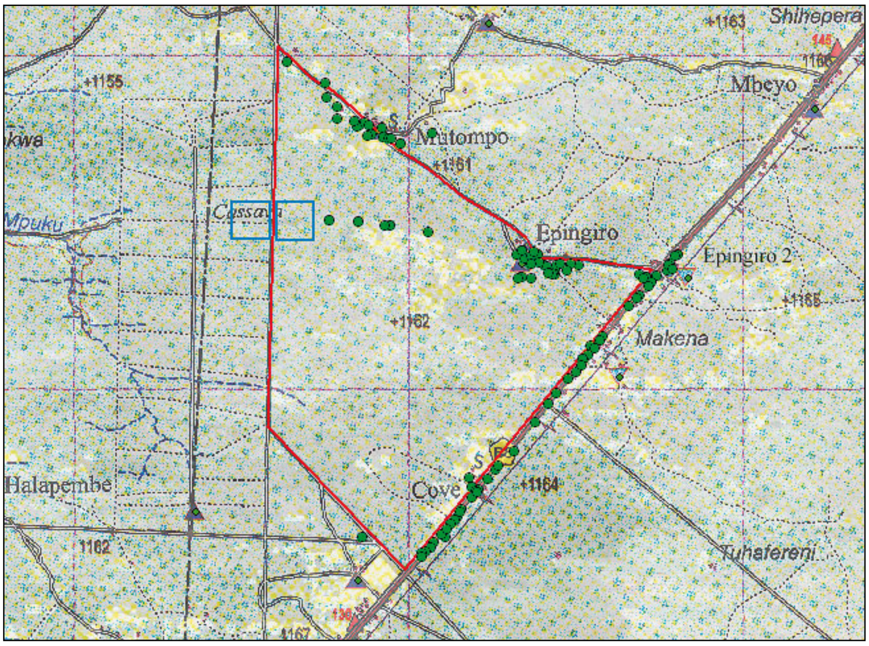

Fig. 1: The core research area with Observatories, villages and census territory. Red polygon = census territory, blue squares = BIOTA Observatories, green dots = households, in 2005. Source: Pröpper (2009a).

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.

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).

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.

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

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

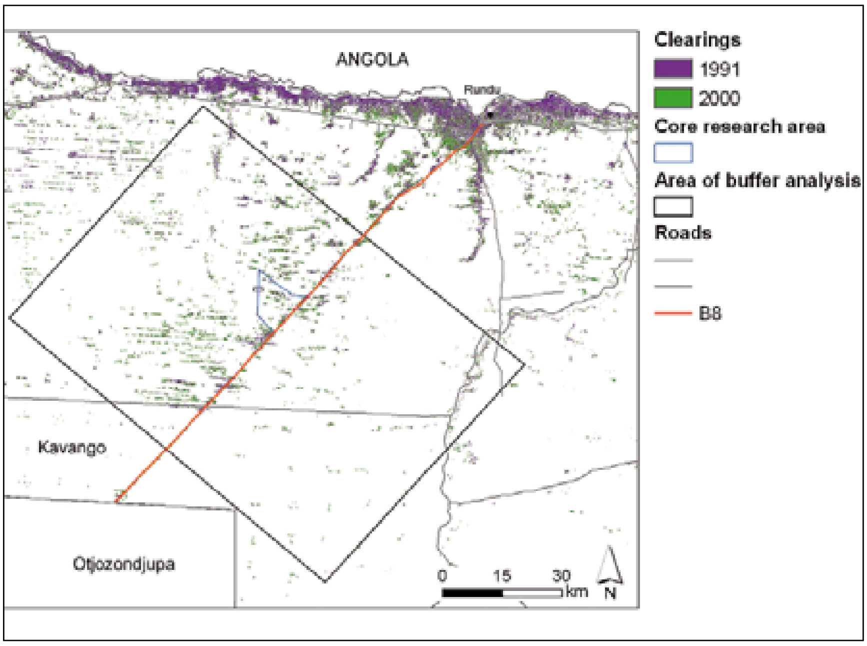

Fig. 2: The spatial extent of clearings in the central part of the Kavango Region for the year 1991 (in purple) and further expansions until 2000 (in green). A buffer analysis was performed along the road B8, for the area marked by the black rectangle.

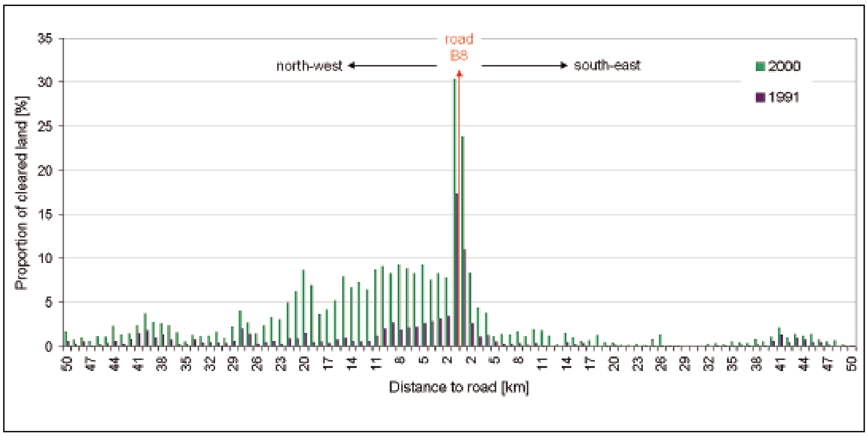

Fig. 3: Result of the buffer analysis along the road (B8) within the area marked by a black rectangle in Fig. 2. The graphic shows the enormous expansion of clearings between 1991 and 2000 especially in a strip approximately 30 km wide north-west of the B8. Each bar represents the proportion of cleared 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 microorganisms. 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 m²) 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

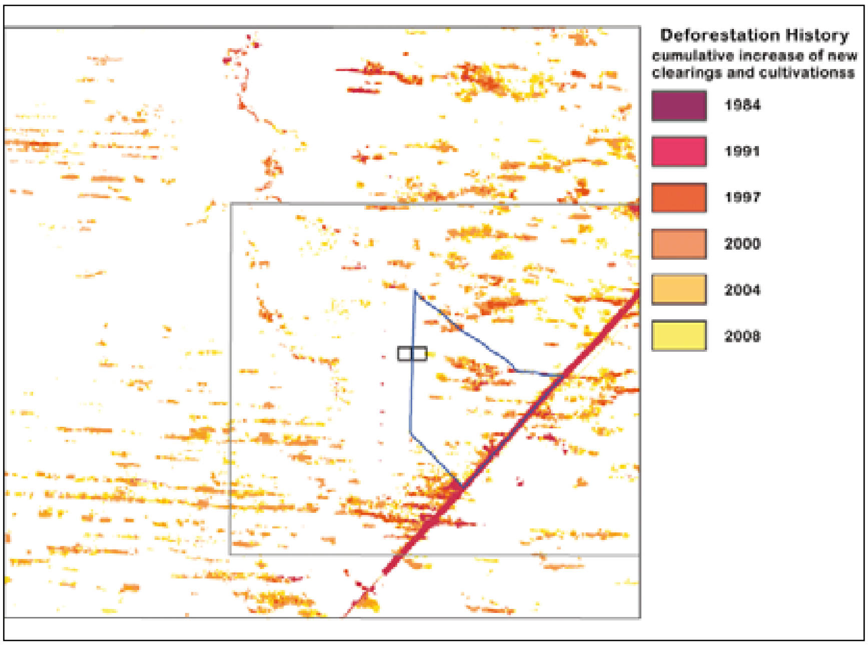

Fig. 4: Development of deforestation in a sub-section of the Kavango Region around the Observatories of Mutompo and Mile 46. Shown is the increase of cleared areas in the period 1984 to 2008, which is derived from Landsat data. The black rectangle marks the detail shown in Fig. 5.

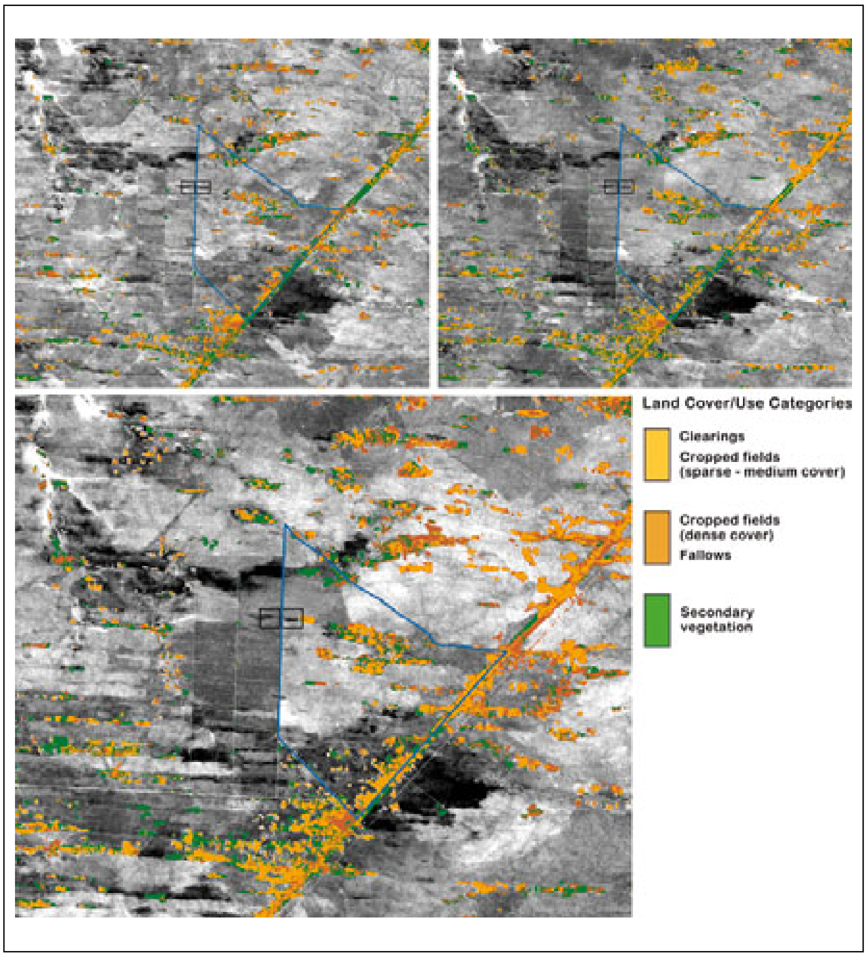

Fig. 5: Status of cultivated and formerly cultivated fields in the area of Mutompo/Epingoro, classified by Landsat data of 2000 (upper left), 2004 (upper right) and 2008 (large picture). In the background, the visible red band (band 3) of the respective Landsat scenes is displayed in greyscale.




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

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

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

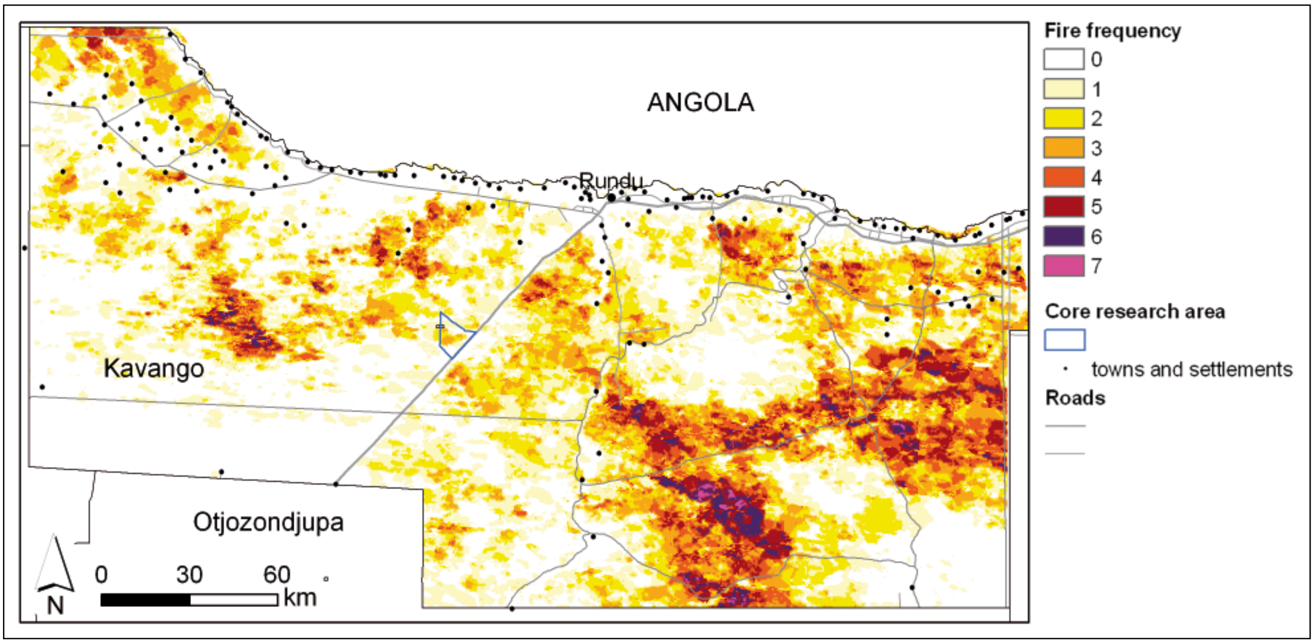

Fig. 6: Frequencies (number of years) of bush fires in the Kavango derived by MODIS time series data from the years 2000, 2002, 2003, and 2005–2008.

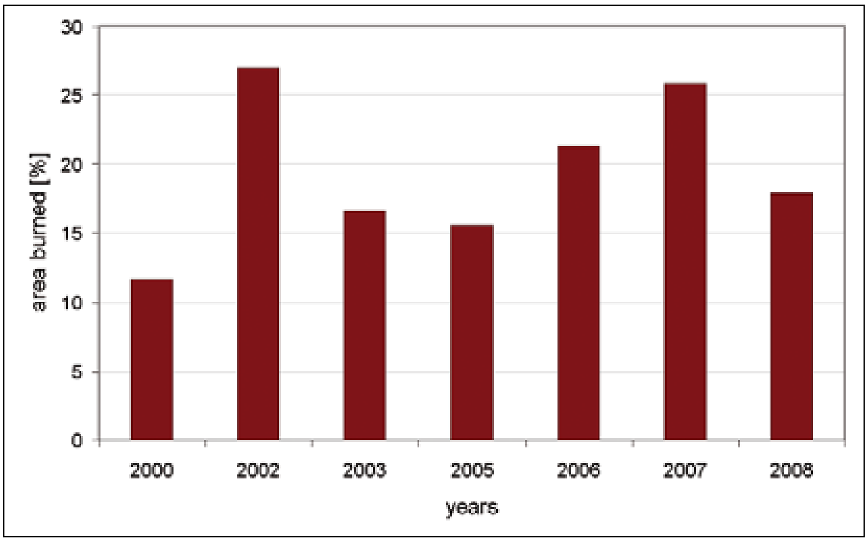

Fig. 7: Percentage of fire affected areas in the Kavango, derived by MODIS time series data, for the years 2000, 2002, 2003, and 2005–2008.

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

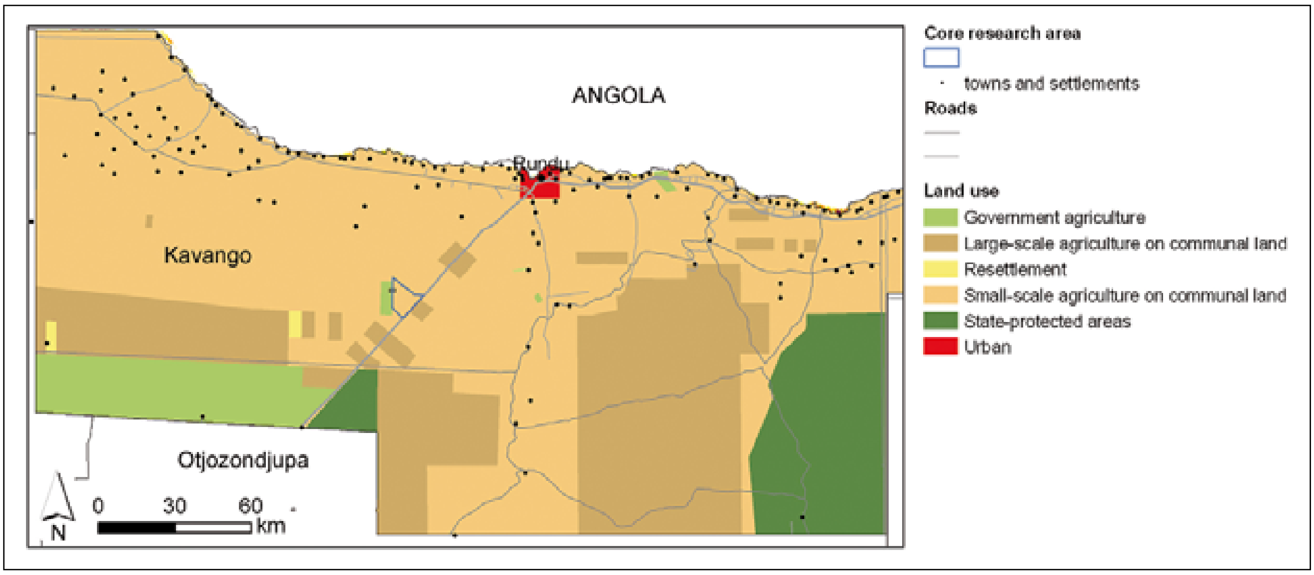

Fig. 8: Landuse systems in the Kavango.

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 µS 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):

- 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

Photo 8: Typical inter-dune crop soil.

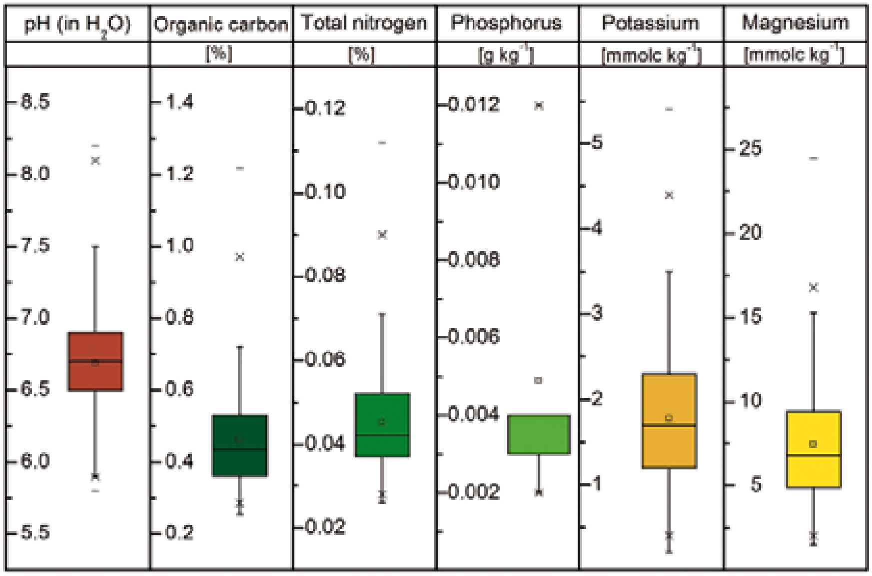

Fig. 9: Soil chemical data of the topsoil.

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

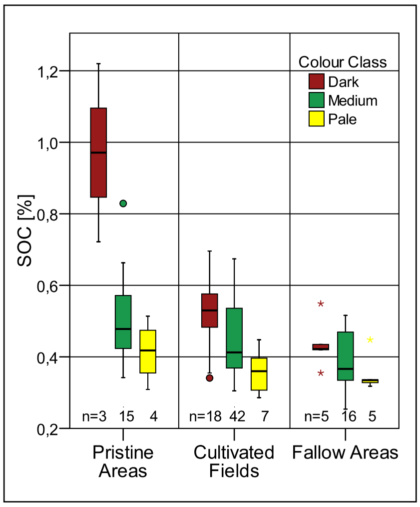

Fig. 10: Organic carbon in the topsoil of dark and loamy, normal inter-dune, and pale sandy sites under three different landuse types.

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.

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).

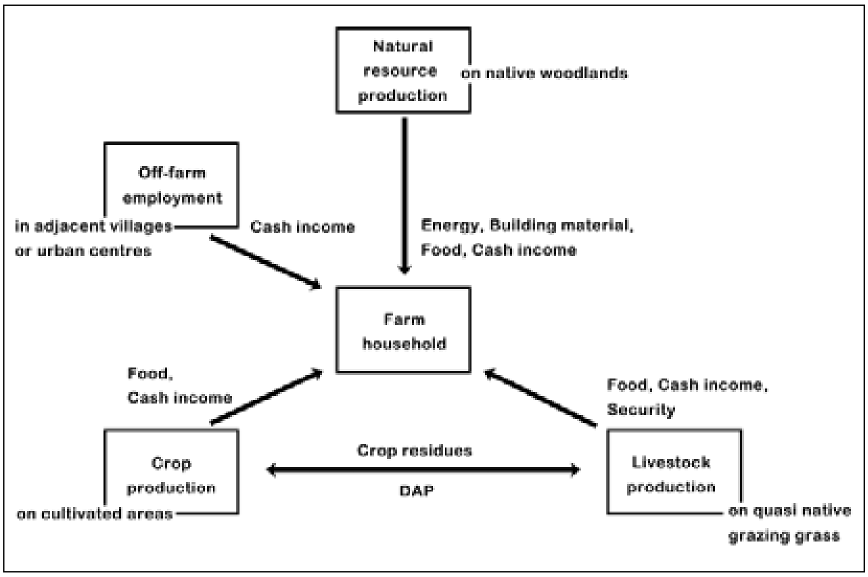

Fig. 11: Major elements of the prevailing livelihood system in the Kavango Region. Modified from Matsaert et al. (1998: 1).

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

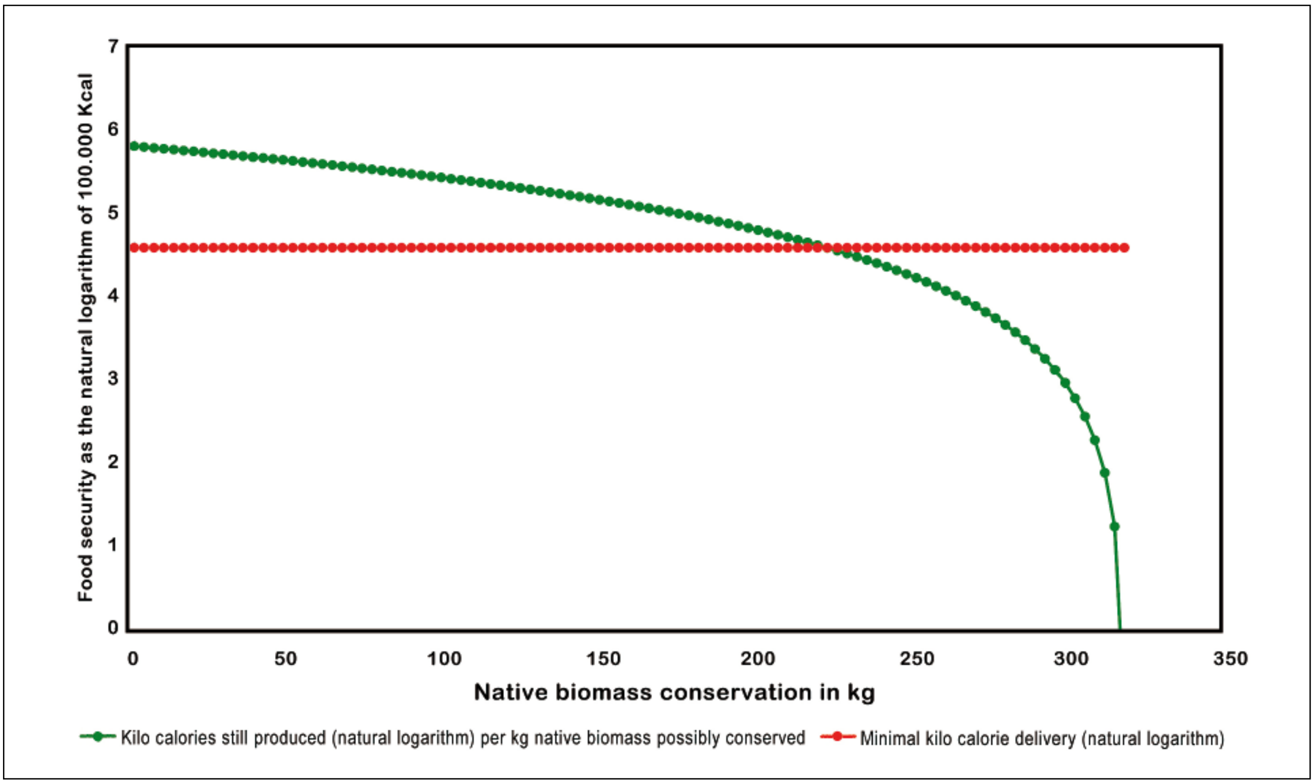

Fig. 12: Trade-off between food security and native biomass conservation under the status quo (baseline scenario). Source: Hecht (2009, based on MAPOM).

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

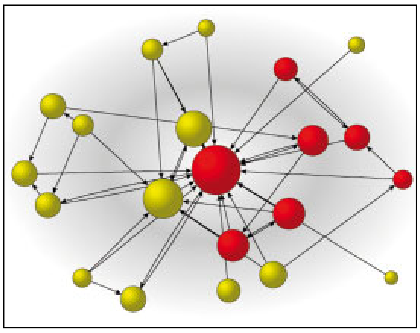

Fig. 13: Complete social network analysis in Epingiro (*N* = 21): whom would you contact in cases of detrimental resource uses? For explanation see text. Source: Pröpper (2009a).

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.

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 landuse 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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