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Settlement, trees and termites in Central North Namibia: A case of indigenous resource management

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Abstract

Current and past settlement strategies in Central North Namibia are explored with historical aerial photographs, maps of indigenous land units (ILUs), GIS analysis, field observations and interviews on indigenous knowledge to improve understanding of livelihood strategies, described as an agro-sylvi-pastoral system. The objective is to assess the role of ILUs, indigenous fruit trees and termites in human settlement. Livelihood strategies take into account unpredictability of the semi-arid environment by having high diversity of ILUs on farm, not by selecting a certain elevation above water level as previously suggested. ILUs are classified according to hydrological properties and other aspects. Farming practices like kraal and homestead rotation and selection of ILUs with pronounced termite activity for cropping are suggested to maintain soil fertility. Selection of termite-rich areas causes a trade-off with homestead longevity and homesteads are located at least termite rich ILUs, but are encroached upon by termites. The amount and distribution of more fertile ILUs causes a trade-off between grazing and cropping when enclosed for farming. It is suggested that indigenous fruit tree species have been encouraged indirectly to grow on farm. It is shown that some fruit tree species never occurred in the area before. This is in contrast with the general view that fruit trees are left when farmers clear land. While some indigenous farming practices may degrade the land, this paper demonstrates that others don't.

Keywords: Indigenous knowledge; Settlement; Resource management; GIS; Indigenous fruit trees

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1. Introduction

Deforestation and forest degradation are generally accepted as being severe in Namibia, especially in the densely populated Central North area (Brown, 1992; Erkkilä and Siiskonen, 1992; Erkkilä, 2001). The same area also suffers from socio-economic and environmental problems acknowledged nationally and internationally as symbols for unsustainable development (Erkkilä, 2001). However, in recent years the environmental degradation discourse for this area is shifting from a scenario of deforestation gloom and doom to a realization that the environment, in the densely populated central area, has changed from a forested area to an agroforestry landscape with many indigenous fruit trees (Kreike, 1995; Erkkilä, 2001).

In the late 1990s, some researchers have studied indigenous management practices in the area mainly concerning farming, grazing and trees (Dayot and Verlinden, 1999; Rigourd and Sappe, 1999; Rigourd et al., 1999; Shitundeni and Marsh, 1999; Verlinden and Dayot, 2000; Hillyer, 2004; Verlinden and Dayot, 2005) using Participatory Rural Appraisal approaches (Chambers, 1994).

These studies indicate that an elaborate indigenous knowledge system about the environment exists resulting in a classification of indigenous land units (ILUs). This recognition was followed by studies exploring the possibility of linking this indigenous knowledge system with conventional scientific classifications and observations in a participatory GIS (Verlinden and Dayot, 2000; Hillyer, 2004). It appears that the presence, distribution and abundance of the land units, are more decisive factors in farmers' resource management strategies than previously thought (Lechevallier and Weill, 2001; Hillyer, 2004). The knowledge appears to be very widespread and not specific to gender, wealth or age. The local knowledge systems do not differ to a great extent from conventional knowledge (Hillyer, 2004). In agriculture dominated areas the classifications are the result of an elaborate understanding of the ecohydrology of the environment. The main farming strategies are explained by this understanding of the dynamics of water transport through the environment in response to rainfall (Hillyer, 2004). The performance of various units with different rainfall scenarios is well known by local people (Verlinden and Dayot, 2000).

In grazing areas subdivisions of main units emerge from differences in vegetation structure and indicator species (Verlinden and Dayot, 2005). The participatory approach developed with farmers improves the understanding of rural livelihood strategies at individual and community level. The main advantages of the methodology over conventional methods are: the use of a common language and understanding of the environment, the possibility to map neighboring areas by using remote sensing and much more detail and precision of classification at farming level. The work highlighted the importance of rules and norms for the management of scarce resources, previously unrecognized. These norms are adapted to local changes in conditions such as rainfall, surface water availability, grazing quality and new opportunities. The norms point to the existence of a social organization within communities regarding use and control of resources (Verlinden and Dayot, 2005). The indigenous environmental knowledge and it's classification is a response to the unpredictability of the environment. In such an unpredictable environment the settlement patterns and farming strategies in Central North Namibia can be considered as safe bets. Farmers are not avoiding risk, but managing resources with a high—but largely known—degree of unpredictability.

This study builds on previous research by focusing on settlement strategies with an emphasis on the role of ILUs, indigenous fruit trees and termites. This is done with a variety of tools, including the analysis of historical aerial photographs starting from 1943, PRA techniques to assess and understand local perceptions on land use, land suitability and resource management, GIS and field measurements. As the role of ILUs in farming strategies rests on the research of only two different areas (Lechevallier and Weill, 2001; Hillyer, 2004), studying the settlement patterns and strategies of different environments in the area enables an analaysis of their differences. Such analyses are much needed in rural Africa where resource use patterns diverge greatly from those associated with western agriculture and ranching systems (Turner and Hiernaux, 2002).

In previous studies elevation was thought to be an important criterion for settlement choices (Erkkilä, 2001), while Verlinden and Dayot (2000) suggest that the soil depth above a hardpan is more important. Hard pans, common in the study area, are formed at differing depths from the soil surface and these depths are not necessarily related to elevation. Many ILUs are defined by local people according to the presence and the depth (within a range) of the hard pan from the soil surface. This study explores whether overlaying maps locating indigenous fruit trees with ILU maps, gives more meaningful results than previous elevation models.

Also the role of indigenous fruit trees in settlement strategies is debated. Generally, it is accepted that farmers leave fruit trees when clearing land (Erkkilä and Siiskonen, 1992), but some information in Kreike (1995) and Erkkilä (2001) suggest that some trees in the study area may have been planted or certain management practices used to encourage the regeneration of specific species. Up until now, the extent to which these practices may have modified the distribution of such species is unknown. Not only do indigenous fruit trees play an important role in the farming systems of Central North Namibia (Marsh, 1994) but also, in the case of *Sclerocarya birrea*, within the culture and livelihoods of local people (Botelle et al., 2002; den Adel, 2002). It is therefore likely that settlement strategies are influenced by the distribution of this species.

The possible role of termite distribution within settlement strategies is also poorly understood and documented. McDonagh and Hillyer (2001) report higher phosphate levels in soil samples taken from old termite heaps. Given that soils across Central North Namibia are uniformly low in phosphorous the higher levels may explain farmers expressed preferences for farm land containing termitaria Hillyer (pers. comm.) and Verlinden and Dayot (2000). In northern Malawi, Verlinden et al. (2003) found that termitaria play an important role as fertilizer in traditional farming practices.

2. Materials and methods

2.1. Study area

Fig. 1 shows the location of surveyed areas in Central North Namibia. Different symbols are used to distinguish areas surveyed with a different emphasis. The ILUs of all 13 areas were studied using participatory assessments of their potentials and constraints.

Selection of the surveyed areas was largely based on focus areas that were defined during workshops with local experts in a Farming Systems Research and Extension (FSRE) project. The main purpose was to find areas representative of different combinations of

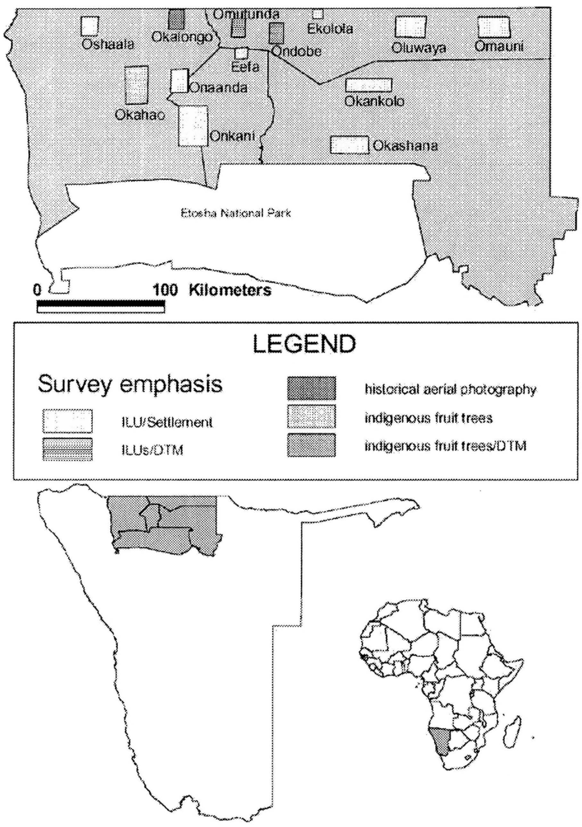

Fig. 1. Location of the surveyed areas in Central North Namibia with different symbols for the different types of surveys: ILU/Settlement are areas where the emphasis was on settlement patterns in relation to ILUs; ILUs/DTM are areas where the emphasis was on relationships between ILUs and Digital Terrain Models; historical aerial photography are areas where aerial photographs were used to detect changes in environment; Indigenous fruit trees are survey areas where the emphasis was on field measurements of fruit trees on farm and Indigenous fruit trees/DTM is the area where the emphasis was on relationships between measured fruit trees and a DTM. The map below indicates Namibia with the study area and the insert shows the location of Namibia in Africa.

characteristics that are important in Central North Namibia. They are based on differences in: population density, main ecosystem, water supply, grazing pressure, land availability and presence of cattle posts. Areas on the boundaries between the main ecosystems the Cuvelai basin, the Kalahari Sandveld, the southern Plains and the Etosha Pan were also included. It was considered that having access to two different systems was likely to affect local livelihood strategies. Table 1 lists the key selection criteria for each focus area.

While in nine areas the ILUs were mapped, in two other areas detailed measurements were taken of indigenous fruit trees on farm; in Okahao 23 farms and in Ondobe 20 farms were measured. Okahao, located in the Western Cuvelai basin, has more saline soils with underlying hard pans and was settled relatively recently. Ondobe, located in the Eastern Cuvelai, has deeper non saline soils and was settled more than 60 years ago. In these cases settlement period was important as the main purpose was to investigate the differences in

Table 1
Criteria for the selection of surveyed areas

Survey area	Population density	Ecosystem	Water supply	Grazing pressure	Cattle post
Omauni	vl	Kalahari sandveld	Borehole	vh	Yes
Oluwaya	l	Kalahari sandveld	Borehole	h	Yes
Okankolo	l	Kalahari sandveld	Shallow wells	m	No
Okashana	vh	Boundary Kalahari-Etosha	Wells and pipeline	h	Yes
Onkani	l	Boundary plains-Cuvelai	Pipeline	m	Yes
Ekolola	m	Boundary Cuvelai-Kalahari	Shallow wells	h	No
Ondobe	h	Eastern Cuvelai	Pipeline	l	No
Eefa	vh	Central Cuvelai	Pipeline	vl	No
Omatunda	vh	Central Cuvelai	Pipeline	m	No
Onaanda	m	Central Cuvelai	Pipeline	l	No
Okalongo	vh	Western Cuvelai	Pipeline	l	No
Okahao	h	Boundary Western Cuvelai-Kalahari	Pipeline	h	No
Oshaala	m	Western Cuvelai	Shallow wells	l	No

Abbreviations: vl: very low; l: low, m: medium; h: high; vh: very high.

population structure of indigenous fruit trees. Detailed Digital Terrain Models (DTM) were built for two areas where elevation data were available: Omatunda in the Central Cuvelai and Ondobe. Both areas occur on the same latitude and both have been settled for a long time. However Omatunda has more saline soils with underlying hard pans. Similar to Omatunda is the Okalongo area in the Central Cuvelai, which has been used for a comparison of aerial photographs through time from 1943 to 1992. Sadly, only a narrow portion of the Angola-Namibian border was photographed in 1943. It is nevertheless a very important dataset as the scale and quality of the photography is quite good.

Habitat and environmental conditions across Central North Namibia are highly variable but reliable data on fundamental ecological parameters, agro-meteorological data and the variation within regions are scant (Hutchinson, 1995; Matanyaire, 1995; EDG, 1996). Northern Namibia is situated at the interface between the Inter-Tropical Convergence Zone and the Mid-Latitude High Pressure Zone. Slight inconsistencies in the extent or timing of the movement of these zones causes considerable difference to the weather experienced from one year to the next. Approximate rainfall isohyets indicate a range of annual precipitation of between 350 in the Southwest and 550 mm in the Northeast. In Ondangwa, the centre of the study area, the annual rainfall during 1959–1973 varied from 200 to 1039 mm with an average of 495 mm. There are three seasons: cold dry—May to August; hot dry—September to December, hot wet—January to April. There is great variation in day and night-time temperatures. In winter, the night temperatures drop to 7 °C with day temperatures rising to 27 °C or higher. During the hot season, the soil temperature may rise above 36 °C, causing severe stress to plants.

Surface water is mainly found in the central Oshana area. Oshana is the local name for floodplains of an inland drainage system called the Cuvelai with a surface area of 7 000 km^2. Water flow in the oshanas differs from year to year and place to place. When there is a lot of rainfall in Angola, the central oshanas might flow for several months.

Oshana water flow and direct rainfall both contribute to shallow ground-water recharge (van der Waal, 1991). Fresh surface water is of high quality but is erratic and when available, is only temporary.

Three major ground-water areas occur in the study area. Potable water is found in the eastern and western deep aquifers and in the shallow aquifers of the Brine Lake area, situated in the centre of the study area. Ground-water in the East and West of the Oshana area less saline and boreholes for watering livestock and for human consumption are found in those areas. Ground-water in the Oshana area occurs in three discrete compartments: a discontinuous perched aquifer, the main shallow aquifer and a saline deep aquifer. In the northern part of the oshana area, the discontinuous perched aquifer provides a limited amount of water at shallow depths. Conical hand-dug pits (omafima) tap this ephemeral resource. The main shallow aquifer is located within the Kalahari sandstones at depths of less than 25 m and this water is usually tapped with hand dug-wells, the quality varies from drinkable to highly saline (Marsh and Seely, 1992), especially towards the end of the dry season. In recent years the supply of clean water, to the central area via a pipeline system distributing water from the Kunene River in Angola, has been a high priority.

The soils are mainly deep Kalahari sands of poor fertility (Marsh and Seely, 1992). They are poor in organic matter content (0.2–0.9% organic C), have very low cation exchange capacity (1–1.5 meq/100 mg) and low base saturation (30–45%). Except for ILUs associated with termite activity where phosphorus levels are relatively high (P-Bray 35 mg/kg), available phosphorus is low (P-Bray 2–7 mg/kg) (McDonagh and Hillyer, 2001).

Within those vast expanses of deep sands in the East, are many pans containing clayey sands of a higher nutrient content. Loamy sands of higher nutrient content are also found on the dune tops in the inverted Kalahari sand dune system in the East (Thomas and Shaw, 1991). As a result of repeated flooding clayey sodic sands dominate the central Oshanas and less sodic sands occur on the surrounding higher ground (Mendelsohn et al., 2000). Hard layers of clay, often rich in salts, form between 10 and 100 cm below the surface in many places. These hardpans play an important role in potentials and constraints of the soils for various crops (Verlinden and Dayot, 2000; Nott et al., 2003; Hillyer, 2004; Verlinden and Dayot, 2005). To the West of the Oshanas, deep Kalahari sands with some large calcrete pans dominate the environment. Many soils are weakly structured and therefore susceptible to crust formation and wind erosion.

Mendelsohn et al. (2000) described and mapped 35 different vegetation types for the study area. Table 2 lists the vegetation types found in each of the surveyed areas according to this vegetation map. Listed also are relevant attributes regarding suitability for cropping and grazing, species diversity and general condition according to Mendelsohn et al. (2000). It is important to note that many of these listed units are mosaics of smaller, discrete vegetation types. The tree species nomenclature used in this paper follows that of Coates-Palgrave (2002).

2.2. *Aerial photography*

In the study area there have been several projects in which aerial photographs were used for a systematic land survey. The first one was conducted in 1943 and covers the Namibian-Angolan border extending about 20 km southwards. The photographs have a photoscale of about 1:30,000. In 1970 and 1972 aerial photos of a scale of 1:50,000 were

Table 2
Vegetation types, soils and general suitability of the environment of the surveyed areas for growing crops, pasture quality and degree of salinity

Area	Vegetation type	Soils	Crops	Pastures	Salinity
Omauni	Burkea Baikiaea woodlands on grey sands	Sands	L	m	vl
Omauni	Dense Baikiaea woodland	Sands	Vl	m	vl
Omauni	North-eastern pans	Clayey sands	H	m	m
Okankolo	Burkea Combretum savanna	Sands	L	l	vl
Okankolo	Burkea Baikiaea woodlands on grey sands	Sands	L	m	vl
Okankolo	Burkea Terminalia sericea shrubland	Sands	L	l	vl
Okankolo	Omuramba drainage system	Sandy clays	H	l?	l
Okashana	Etosha steppe	Loams or Loamy sands	Vl	m	vh
Okashana	Terminalia prunioides/sericea wood a	Sands	L	m	vl
Onkani	Mopane shrub and low trees on Loamy sands	Loamy sands	L	l	m
Onkani	Oponono saline grasslands	Sodic sands	Vl	m	vh
Onkani	Oshanas	Clayey sodic sands	Vl	l	h
Onaanda	Mopane shrub and low trees on oshanas	Sodic sands	M	l	m
Onaanda	Oponono saline grasslands	Sodic sands	Vl	m	vh
Onaanda	Oshanas	Clayey sodic sands	Vl	l	h
Okahao	Cuvelai palms and fruit trees on Loamy sands	Loamy sands	H	vl	l
Okahao	Mopane Combretum savanna on sandy soils	Sands	H	m	vl
Okahao	Mopane shrub and low trees on Loamy sands	Loamy sands	L	l	m
Okahao	Mopane shrub and low trees on oshanas	Sodic sands	M	l	m
Okahao	Oshanas	Clayey sodic sands	Vl	l	h
Oshaala	Cuvelai palms and fruit trees on Loamy sands	Loamy sands	H	h	vl
Oshaala	Mopane shrub and low trees on oshanas	Sodic sands	m	l	m
Oshaala	Mopane	Sodic sands	vl	vl	vl
Oshaala	Oshanas	Clayey sodic sands	vl	l	h
Okalongo	Mopane	Sodic sands	h	l	m
Okalongo	Oshana-Kalahari mosaic	Sodic sands	h	l	m
Okalongo	Oshanas	Clayey sodic sands	vl	l	h
Omatunda	Oshana-Kalahari mosaic	Sodic sands	h	l	m
Omatunda	Oshanas	Clayey sodic sands	vl	l	h
Eefa	Oshana-Kalahari mosaic	Sodic sands	h	l	m
Eefa	Oshanas	Clayey sodic sands	vl	l	h
Ondobe	Burkea Baikiaea woodlands on grey sands	Sands	l	m	vl
Ondobe	Oshana-Kalahari mosaic	Sodic sands	h	l	m
Ekolola	Burkea Baikiaea woodlands on grey sands	Sands	l	m	vl
Ekolola	North-eastern pans	Clayey sands	h	m	m

Abbreviations: vl: very low; l: low, m: medium; h: high; vh: very high.

used for topographical mapping. In 1992 a portion of the study area was photographed at a scale of 1:30,000. In 1996 the whole country was photographed at a scale of 1:78,000. In all these projects panchromatic film was used. The aerial photographs from 1943, 1992 and 1996 were selected for this study, noting that the first two sets did not cover all the surveyed areas.

The aerial photography of 1992 was used for detailed topographic mapping by a Finnish project and the available digital data with height estimates was used to construct a detailed digital terrain model (DTM) for two sample areas, Omatunda and Ondobe. As the whole area is fairly flat with elevation differences of less than 15 m, available DTM data with a resolution of about 20 m in height could not be used. The digital data with height readings included spot heights, contours, fencelines and homesteads. These were used to compile a detailed set of spot heights. These spot heights were converted to a DTM using a cubic equation of 12 closest points for spline smoothing. This method keeps the original heights from the point samples. The area has a typical gradient of 1:10,000—a drop of 1 m for every 10 km—with a general slope north–south (Botelle et al., 2002). Investigations on the influence of elevation on farm selection were carried out in small areas to avoid unaccounted impact of this slope.

Tree measurements from 43 farms were used to ground truth interpretations of trees in the photographs of 1992 and 1996. These interpretations suggest that indigenous fruit trees with large diameter canopies were mainly, or only occurring, within the fenced areas of farms. The historical aerial photographic dataset was used to explore this. All aerial photography was scanned to a resolution of 1–1.5 m and registered when necessary. The 1943 photographs were used to digitize the farms that were established at the time. The 1992 photography was used to digitize canopy diameters of the visible trees on established fields, excluding trees that were outside ploughed fields. Regression analysis, between measured canopy diameters of trees and digitized canopy diameters of the same trees on the aerial photographs, was used to test the validity of the digital results. A GIS was then used to differentiate between trees growing on fields that were already established in 1943 and trees growing on fields that were not established as farms in 1943, in the Okalongo area. A comparison was then made of the canopy diameter distribution between the two samples of trees. Termite heaps that were visible on the1943 and 1992 photographic mosaics were also digitized for the Okalongo area and a further comparison made of the distribution of these termitaria.

2.3. *Field measurements*

All indigenous fruit trees within the fenced farm area were sampled to obtain data on tree size and the density of different species on farms. The following variables were recorded: GPS location and tree number, species and gender, tree height, canopy diameter and trunk diameter at 50 cm from the ground, conforming to the methods described in (Botelle et al., 2002). All fruit trees on 23 farms in Okahao and 20 farms in Ondobe were measured.

2.4. *Interviews*

2.4.1. *Indigenous land units and management*

For this paper, 13 surveyed areas are selected where settlement studies were carried out between 1998 and 2002. Nine of these areas were mapped. Research began with the identification of key informants (150), achieved by holding discussions with community leaders. These key informants were asked to show the team examples of their local landscapes. The team prompted identification of other landscapes encountered during the visits. At each site chosen by the informants, GPS was used to record the location and a detailed description of the vegetation and environmental characteristics were also recorded. Many GPS locations with corresponding ILU names were collected in each survey area and these ILUs were later mapped using satellite imagery and aerial photographs of 1996 as a backdrop in a GIS package.

Group meetings encouraged open discussions on management and resource uses, the influence of ILUs on settlement strategies and the potentials and limitations of ILUs, especially regarding suitability of ILUs for various crops. Notes from these group meetings were later discussed by the team to critically assess the difference between information that concentrated on functional knowledge from that based on belief (e.g. the use of *Croton gratissimus* to protect a home from lightning). Only the functional knowledge was of interest to this study. The influence of termites on settlement strategies was only included in latter stages of the surveys as initially it was not clear that termite occurrence could influence settlement patterns. Finally, feedback community meetings were held in several areas to discuss the findings and the maps that were produced.

After mapping the ILUs, registered aerial photographs were used to digitize farm boundaries, the core of human settlement. Farm boundaries are recognized on aerial photographs because bush fences are used to demarcate them. Farms and particular farm boundaries are allocated by the headman to families. Land may also be inherited based on a matrilineal system or reallocated to other families.

2.4.2. Indigenous trees and management

Semi structured interviews were held in Okahao and Ondobe (Fig. 1) with 43 individual farmers. The following topics were covered: General issues (name, gender, social status, when the farm was settled, income generation, importance of pensions, remittances), relationships between ILUs and farming practices, including relationships between trees and ILUs, tree management (planting, tending, cutting of trees, no management), uses of various natural resources in and around the farm, the condition of various resources and potentials and limitations of ILUs.

3. Results

3.1. Settlement patterns and ILUs

Fig. 2 shows four samples of settlement patterns marked in Fig. 1. Settlements are identified with farm boundaries against the background of different ILUs. The four samples show the wide variation in settlement patterns in the region.

Area 1 (Omauni) is an example of settlement in the Eastern Kalahari Sandveld. Farms are concentrated around clay-rich pans, although the pans themselves are not used for cropping. The main ILUs targeted for settlement are Ombua-Ekango and Omutunda-Ekango. The first ILU is a relatively open landscape with a duricrust of mainly calcrete at a depth of 0.5–1 m, surrounding a pan. Omutunda-Ekango are elevated areas surrounding a pan, rarely with a shallow duricrust. The topsoil in both ILUs has a heavier texture than the surrounding Kalahari sands and suitable farm land is still available. The farm boundaries are mainly within these units without a pronounced tendency to cover several ILUs in one farm. Omufitu and related ILUs are avoided for farming. Farmers indicated that there is little land left suitable for cropping in proximity to water.

Also located in the Eastern Kalahari Sandveld, sample Area 2 (Okankolo) and 9 (Ekolola) two areas are targeted for settlement: (1) around pans or riverbeds (Omutunda-Ekango) and (2) elevated areas with a heavier topsoil texture (Omutunda and Iitunu). The latter ILUs are often linear landscape elements. The difference is in width, Omutunda are wide, while Iitunu are narrow, often not wide enough to establish a field. Area 2 is a typical

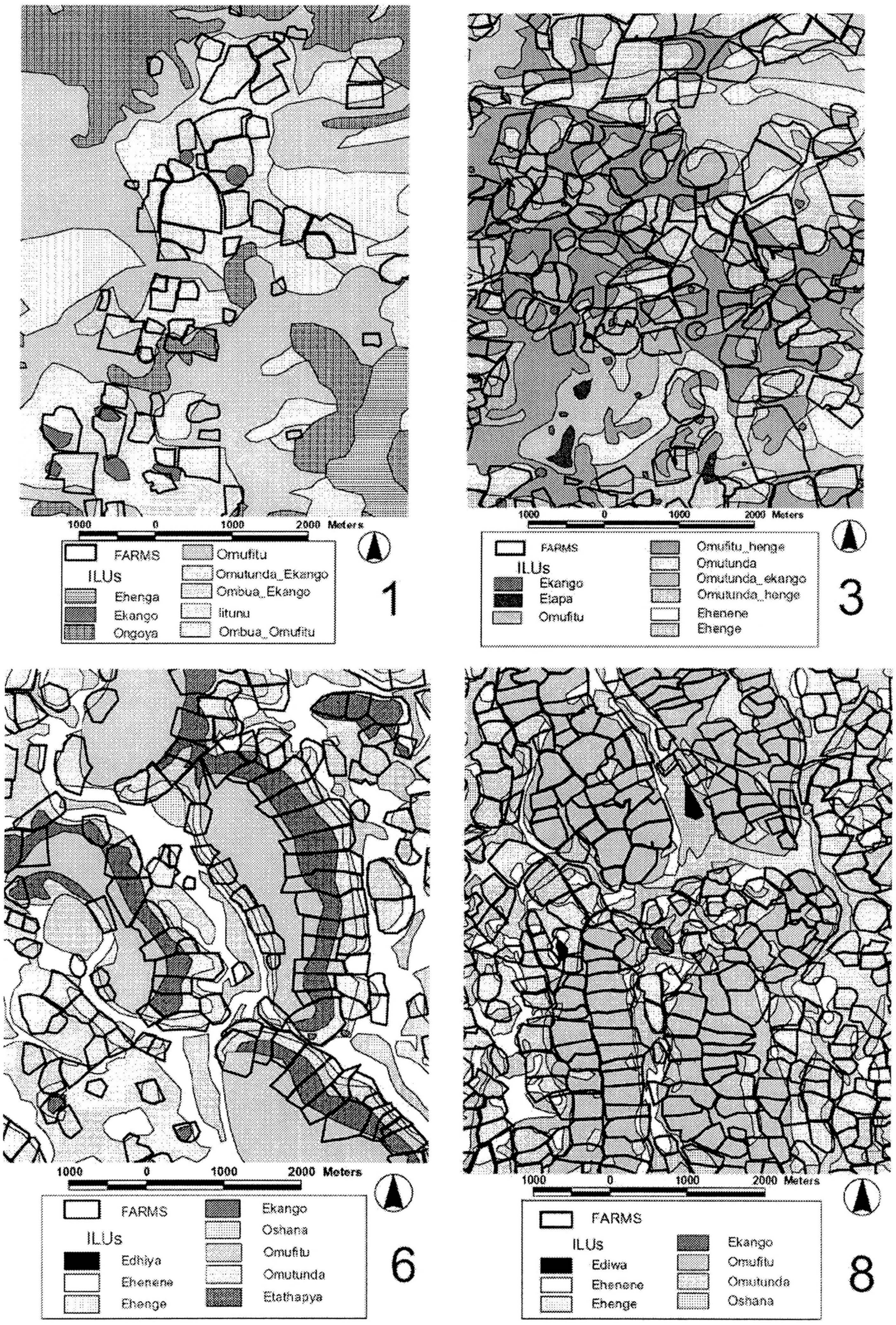

Fig. 2. Settlement patterns mapped from 1996 aerial photographs in survey areas, located in Fig. 1. Numbers refer to samples areas: 1: Omauni, 3: Okashana, 6: Oshaala, 8: Eefa. The first two areas are outside the Cuvelai but Area 1 has a low and Area 3 a very high population density. The last two areas are typical for the Cuvelai with Area 6 a medium and Area 8 a very high population density. The ILUs form the background of the maps. Area: The main characteristics of the areas and ILUs are explained in Tables 3 and 4. Farm boundaries were digitized on 1996 aerial photography.

example of settlement in the inverted Kalahari dune system, where the current elevated areas have a heavier topsoil texture. There is no pronounced tendency of the farms to cover several ILUs, although farmers recognize several subunits within the ILUs suitable for cropping and sow different varieties of melons in these units. There is still some suitable land available for cropping although farmers indicated increased settlement would seriously reduce good grazing land.

Although Area 3 (Okashana) (Fig. 2) was settled as recently as the early 1980s, population density is very high. The cattle posts (Table 1), usually associated with low population densities, are in a grazing reserve south of the area. Omutunda and Omutunda-Ekango are again considered most suitable for cropping, but in contrast with Area 1, 2 and 9 there is a clear tendency of farmers to incorporate several ILUs on one farm. Combinations of Omutunda, Omutunda-henge and Omutunda-Ekango are very common, while also Ehenge can be included.

Area 6 (Oshaala) (Fig. 2) is on the western end of the Cuvelai drainage system and first settlers mentioned that the area was a cattle post area until the early 1960s when permanent settlement began. Livestock are still an important component of the livelihood strategies of many people living in the area. Early settlement had a marked pattern along the sandier elevations between the Oshanas. Due to the use of manure, household and kraal rotation in the field an anthropogenic ILU, called Etathapya has come into existence (Hillyer, 2004) in the central portion of the gradient between Oshana and dune crest. Although far less suitable for crops during most rainfall scenarios, farmers have included the ILUs Oshana and Omufitu on their farms as the extremes of a wide range of ILUs. Up to seven ILUs can be included in the cultivated area.

Area 8 (Eefa) (Fig. 2) shows similarities with area 6 in settlement pattern with narrow farms encompassing several ILUs along the gradient between Oshana and Omufitu. A higher population density compared with area 6 results in more rather unsuitable areas for farming being settled in areas 7 and 8. Some farms are found entirely on Omufitu and are smaller in size. Large livestock herds are rare in areas 7 and 8 than in area 6 and farmers frequently mentioned a shortage of manure in the area with a loss of soil fertility, indicated by the lighter color of the local soils. No Etathapya was identified by the farmers in areas 7 and 8, possibly as a result of insufficient livestock and manure. Elements of the original settlement of Area 6 are still recognizable in Area 8 but it seems that population pressure has forced farmers to enclose land previously considered unsuitable for farming. Some farmers mentioned that the ILU Ehenge was on the increase in the central areas of the Omufitu. Many farmers in the area have no livestock or manure and soil fertility is recognized as a major problem. Generally, Fig. 2 suggests that settlement can be explained by: proximity to water, the presence and spatial distribution of preferred ILUs and combinations thereof, and the availability of grazing land for that portion of the population that rear cattle as their main livelihood strategy.

Table 3 summarizes a GIS analysis of the nine mapped areas with respect to: total size of area, percentage of area occupied by farms, percentage of ILUs in the area, and percentage of each ILU occupied by farms. The areas have been listed with lowest population density on the left and highest population density on the right, as indicated by the percentage of the area enclosed by farms. The ILUs have been grouped in 3 according to: (1) presence of temporary surface water or shallow ground-water, (2) lack of soil fertility and (3) soils with higher fertility.

Table 3
GIS analysis of nine areas where Indigenous Land Units (ILUs) were mapped

Area number	1	4	2	9	5	6	7	8	3
Total area of study area (ha)	29718	14612	35164	13578	16408	18709	21672	23733	12876
% of total area occupied by farms	5	12	15	16	36	43	54	64	67
ILUs with surface water									
Edhiya % area				0	0	0	0	0	
Edhiya % farm				57	39	12	43	37	
Ekango % area	0		3	2	3			1	1
Ekango % farm	42		22	19	7			8	57
Olutha % area					0				
Olutha % farm					35				
Ondombe % area						0			0
Ondombe % farm						32			74
Oshana % area					2	9	15	18	
Oshana % farm					8	4	11	31	
ILUs with infertile sand									
Omufitu % area	21	2	22	49	10	13	14	20	
Omufitu % farm	2	6	2	1	39	27	69	76	
Ehenga % area	5								
Ehenga % farm	0								
Ehenge % area			5	0		6	8	3	7
Ehenge % farm			4	44		64	66	49	67
Ehenge-omusati % area									5
Ehenge-omusati % farm									62
Ombua-omufitu % area	21								
Ombua-omufitu % farm	1								
Elondo % area			15	14			1		
Elondo % farm			3	6			72		
ILUs selected for cropping									
Ombua-ekango % area	2								
Ombua-ekango % farm	50								
Ehengefitu % area		5					1		8
Ehengefitu % farm		33					72		54
Omutunda % area			25	7	42	32	35	47	19
Omutunda % farm			18	35	64	54	75	80	66
Omutunda-ekango % area	6		23	24					3
Omutunda-ekango % farm	44		37	48					64
Omutunda-henge % area									17
Omutunda-henge % farm									73
Omutunda-henge sati % area									29
Omutunda-henge sati % farm									72
Omutunda-sati % area									5
Omutunda-sati % farm									78
Omutunda-ombuga % area		14							
Omutunda-ombuga % farm		24							
Etathapya % area						16			
Etathapya % farm						83			

Legend to abbreviations: % area, the percentage of the total area occupied by the ILU; % farm, the percentage of the ILU enclosed by farms; 0: percentage of area lower than 0.5%. Table arranged by increasing size occupied by farms. Area 1: Omauni; area 4: Onkani; area 2: Okankolo; area 9: Ekolola; area 5: Onaanda; area 6: Oshaala; area 7: Omatunda; area 8: Eefa; area 3: Okashana.

The comparison in Table 3 between the area occupied by an ILU within the total surveyed area (by percentage) and the area of the same ILU contained with the farm boundaries of the surveyed area (by percentage) indicates farmers preferences for different ILUs when selecting their settlement location. For example, although the area occupied by water related ILUs occupy only a small percentage of the whole area, a high percentage of them are contained within farm boundaries. The exceptions are Ekango and Oshana that are saline, in areas where salinity is an acknowledged problem.

In areas of low population density, soils with low fertility (usually those on deep sand) are generally avoided for settling. Whereas Table 3 shows a trend of low fertility ILUs being gradually more occupied with increasing population density. This appears to happen when those infertile ILUs are near more fertile ILUs and are closer to water.

While Table 3 shows that more fertile ILUs are preferred for farming and hence for settlement, no more than 80% of the most preferred ILUs are settled, even in the most densely populated areas. When the more fertile ILUs are abundant, enclosure is relatively small. An example is in Area 8, where the most preferred ILU, Omutunda occurs across 47% of the area and 80% of this area is enclosed within farm boundaries. On the other hand Omufitu, avoided by some for farming, accounts for only 20% of the total area while 76% of this area is enclosed. Noteworthy is that Area 8 is a very diverse landscape whereas Area 5 (Onaanda), is a less diverse landscape with a medium population density. In Area 5 Omutunda occupies 42% of the total and only 64% is enclosed, while Omufitu occupies 10% of the total area and 39% of this is enclosed. This suggests that less fertile ILUs must play a role in the choice for settling, otherwise settlement would concentrate only on the most fertile ILUs.

Many farmers indicated that the proportion of the more fertile ILUs that were enclosed is important for the sustainability of livestock rearing. During discussions it appeared that farmers encountered in Area 2, had moved out of Area 9 because of the shortage of grazing land. However, Table 3 shows that there is only a 1% difference in these areas enclosed by farms, ruling this out as an authentic reason for grazing shortage. The differences between the two areas are found to be in the sizes of the different ILUs. In Area 9, only 31% of the area is classified as more fertile ILUs, whereas in Area 2 the more fertile ILUs account for 54% of the whole area. In Area 9 more than 50% is considered to be poor grazing land (Omufitu, Ongoya), whereas in Area 2 only 22% is considered to be poor for grazing. The degree of enclosure differs so that, more than 30% of the more fertile ILUs are enclosed in Area 9, while only about 20% are enclosed in Area 2. In Areas 3, 7 and 8, there are very few or no large livestock herds around the homesteads but all three of these areas have farm enclosures that account for more than 70% of the most fertile ILUs.

3.2. *Indigenous land units and elevation*

Fig. 3 shows a detailed map of ILUs draped over a Digital Terrain Model (DTM) of Area 7 (Omatunda). Farms boundaries are drawn on the basis of aerial photographs and overlaid on the ILU map. The 3D view demonstrates that most fields and farms are established on slopes while most farms incorporate different ILUs. There is a general North-South gradient so that the areas of the north are a few meters higher than those of the southern portion. The ILUs follow this gradient showing that absolute elevation is not related to ILUs, as previously expected. There are also isolated depressions within the

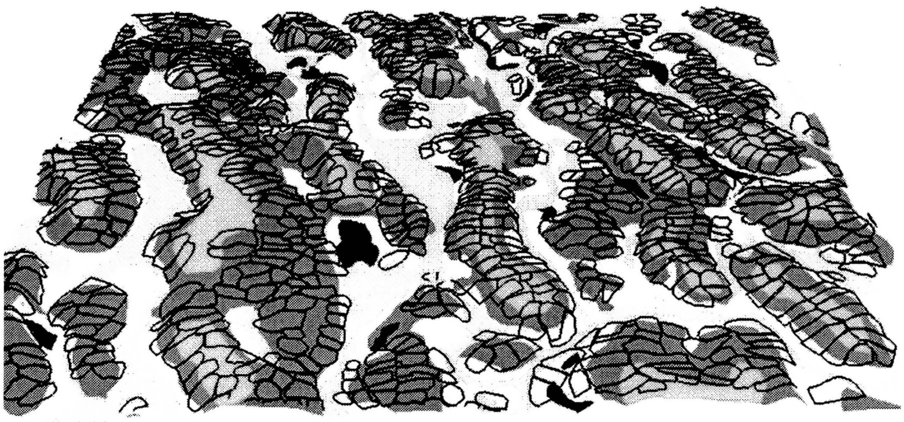

Fig. 3. A three-dimensional view of the influence of elevation on farm establishment and settlement. Different shades of grey indicate different ILUs. Lightest tones indicate Oshanas with Ehenene. Dark grey areas are the Omutunda with lighter Omufitu on the highest areas. Black areas are the Ediwa. Farm boundaries in black are superimposed on the ILU map that is draped over the DTM of Omatunda area (Area 7 in the figure).

dunes that are several meters higher than the comparable Oshanas of the larger drainage system.

3.3. Indigenous fruit trees

Table 4 summarizes the results of the indigenous fruit tree measurements of the two surveys areas Okahao (200 ha) and Ondobe (312 ha). There are large differences between the two areas, in Okahao the palm tree species *Hyphaene petersiana* is dominant, while in Ondobe *Diospyros mespiliformis*, *Sclerocarya birrea*, *Hyphaene petersiana* and *Berchemia discolor* are abundant. The gender ratio differs; the number of females of the more common trees is higher in Okahao. Also in Ondobe, there is a higher proportion of tall trees with larger diameters in the populations of *Sclerocarya birrea* and *Berchemia discolor*.

Fig. 4 compares an area in 1943 with 1992 in the Okalongo study area. In 1943 two farms can be recognized, with two homesteads in the lower left and upper right of the photograph. A few small dark dots representing small trees on fields are visible. Thin lines are brush fences. In 1992, the homesteads are not in the same place and two more farms have been established. Most conspicuous in 1992 are the many large dark dots that are not visible in 1943. It appears that some of the big trees were present in 1943 as small trees. Some small trees in 1943 are still small in 1992. Quite a few large trees in 1992 are not visible at all in 1943, suggesting they established after that time. Small bushes representing *Colophospermum mopane* scrub in the lower portion of the 1943 photograph have been cut and transformed into fields in 1992. Few brush fences are visible in 1992, but two live fences have appeared.

Fig. 5 compares a different area between 1943 and 1992. There were few farms in 1943. The comparison suggests that there were few large trees present in 1943 except in riverine habitat and ponds (Ondombe), while the 1992 photographs suggest that the many large trees are mainly confined to fenced farms.

Table 4
List of indigenous fruit trees measured on farms of the Okahao and Ondobe survey areas

Okahao (200 ha) Species	No.	% female	Height (m)	DBH (cm)
Adansonia digitata	8	100	7.2	384
Berchemia discolor	52	100	5.5	30
Diospyros mespiliformis	3		6	62
Hyphaene petersiana	617	77	2.3	31.5
Sclerocarya birrea	313	77	4.9	38.1
Ziziphus mucronata	15		1.7	
Ondobe (312 ha)				
Adansonia digitata	2	100	10	143
Berchemia discolor	178	98	7.1	44.4
Diospyros mespiliformis	357	57	4.8	28.7
Ficus sycomorus	4	100	9.3	147.3
Hyphaene petersiana	308	55	5.5	43
Sclerocarya birrea	326	61	8	63
Vangueria infausta	108		1.8	
Ximenia spp.	83		2.9	21.5
Ziziphus mucronata	62		5.7	34.5

no = number of individuals counted; % female, the percentage of female individuals; DBH, diameter at 1.3 m in cm.

To determine whether the larger dots on the photographs represent fruit trees with large crown radiuses, a comparison was made between measured crown radiuses of *Sclerocarya birrea* (from farms in Ondobe area) with digitized crown radiuses of the same trees visible on the 1992 aerial photographs. The measurements are highly correlated ($R^2 = 0.71$) (Fig. 6), but the estimated canopy radius derived from aerial photographs is lower than the measured radius. The time difference of 11 years between the photography and field measurements may have contributed to this underestimate. Fig. 6 also suggests that crown radius digitizing on aerial photographs can be used to derive reliable information of crown size distribution.

Distribution of the canopy size of large fruit trees was investigated to discover whether trees found on established farms in 1943 differ from those found on farms in 1992 that were not established in 1943. A sample of 3250 visible trees were digitized on the Okalongo 1992 aerial photographs and then the sample was divided in two groups: those trees found growing on existing farms in 1943 and those trees growing outside established farms in 1943. The resulting crown diameter distribution of the two groups is presented in Fig. 7. The mean canopy diameter of the two groups is significantly different with a much larger number of trees with large crown diameters on farms that were already established in 1943. Mean crown diameter for group 1 (farmed in 1943) is 16.9 m, whereas mean crown diameter for group 2 (not farmed in 1943) is 14.4 m. Kruskal-Wallis ANOVA by ranks $H = 113$, ($N = 3249$), $p < 0.001$.

Fig. 8 shows the crown diameter distribution of *Sclerocarya birrea* in Ondobe and Okahao study areas. The crown diameter distribution in Ondobe is similar to that in the Okalongo area with a large proportion of trees with large crown diameters. However the

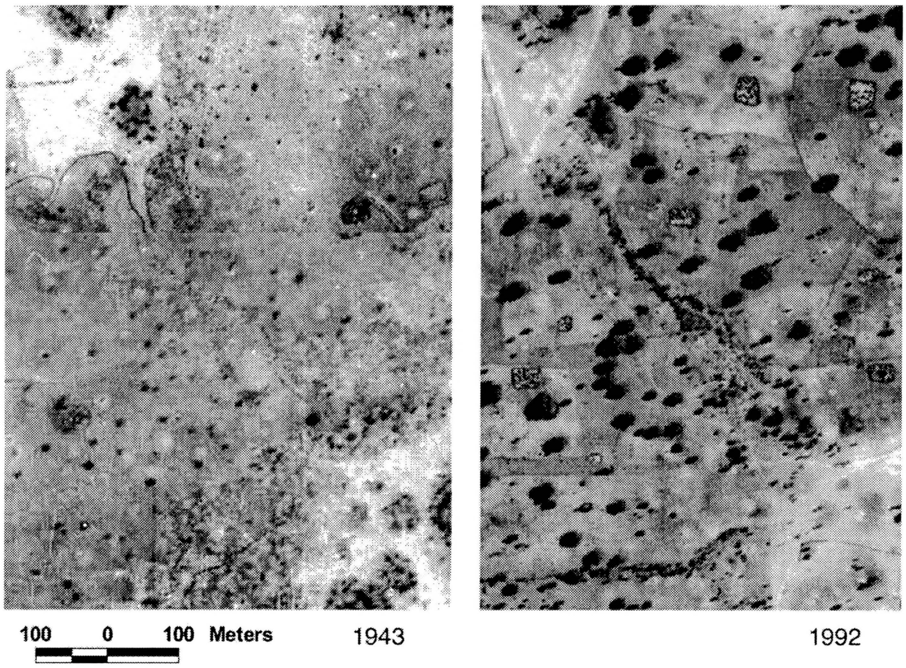

Fig. 4. A close up of the landscape of the same area in 1943 and 1992. Several trees that appear as large dots in the fields of the 1992 photograph are already present in 1943. Some pole fences in 1943 are replaced by live fences in 1992. This is clear in the center and the lower portion of the 1992 photograph. Note that the homestead locations of the same farms are different in the two pictures. Two new homesteads have appeared in the upper portion of the 1992 photograph and two on the right hand side.

crown diameter distribution in the more recently settled Okahao area differs with much smaller trees and a large proportion of very small trees, suggesting there is more regeneration and younger trees in the Okahao area. Interviews suggested that more people in Okahao than in Ondobe want more *Sclerocarya birrea* on their farms.

3.4. Indigenous fruit trees and indigenous land units

The data presented above suggests that many indigenous fruit trees are associated with farms. The four most abundant fruit trees allow an analysis of the occurrence of these species on different ILUs. Fig. 9 presents the number of these trees found on each ILU in the Ondobe area. Of these four trees, most are found on Omutunda, but there are differences in the numbers found on other units. *Berchemia discolor* and *Diospyros mespiliformis* are not frequent on Omufitu, while *Sclerocarya birrea* and surprisingly also *Hyphaene petersian,* (elsewhere associated with more humid environments and soils with a hardpan) are frequent on Omufitu. The high number of *Diospyros mespiliformis* found in Ediwa is as expected since they are naturally associated with more humid environments. Results from population density (number of trees ha^{-1}) present a somewhat different picture because Omutunda and Omufitu ILUs occupy most of the farm land in Ondobe.

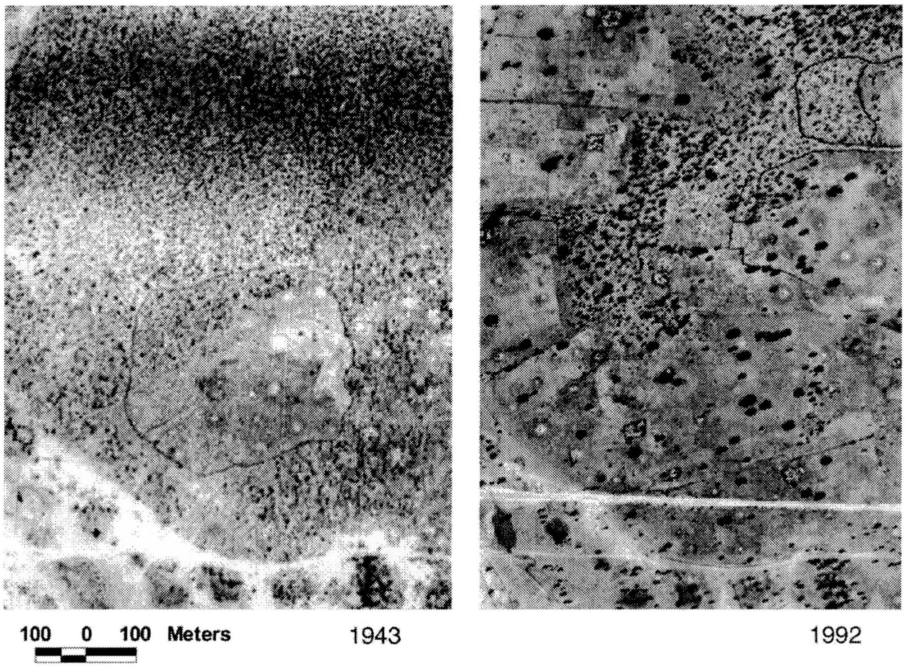

Fig. 5. Areas that were not cleared in 1943 and in 1992 do not have trees as large as those on farm in 1992.

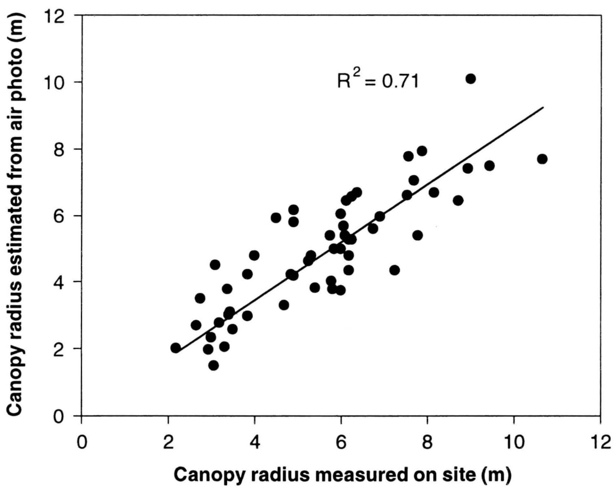

Fig. 6. Regression analysis between canopy radius of *Sclerocarya birrea* measured in the field on farms in Ondobe area and canopy radius estimated by digitizing the same trees on 1992 aerial photographs ($N = 55$).

Fig. 10 suggests that the termite heaps of the Iitunu and the associated ILUs with a harder topsoil (Omutunda and Elondo) have higher densities of the four trees than other ILUs with softer topsoil.

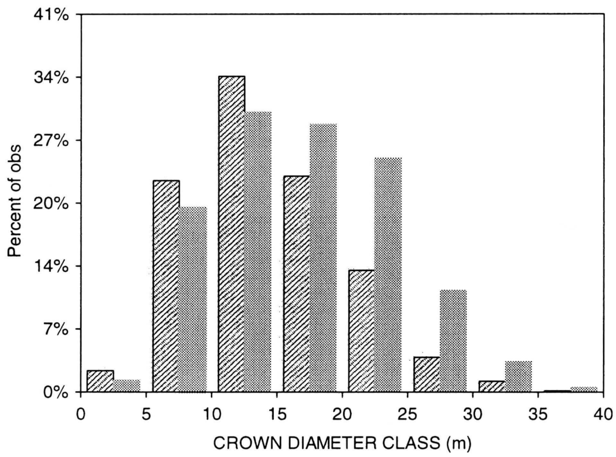

Fig. 7. Comparison of crown diameter distribution of (1) trees on fields in 1992 that were not established farms in 1943 (hatched bars, $n = 1481$) and (2) trees on fields in 1992 that were on established farms in 1943 (filled bars, $n = 1769$).

3.5. Indigenous fruit trees and elevation

To explore whether elevation has an influence on the distribution of fruit trees, the southern portion of Ondobe area was selected to avoid any effects of the minimal North-South gradient of 1 m every 10 km. The results presented are for three fruit tree species that were shown to have a different distribution along the ILUs (Fig. 11). Only *Diospyros mespiliformis* has a clear affinity for lower elevations and is likely to be ground-water-dependent. The fact that some *Diospyros* are found at higher elevations is possibly the result of impeded drainage due to hard layers in the soil profile.

3.6. Termites

Fig. 12 shows large termitaria on 1943 aerial photographs. Similar patterns are also recognizable on the 1992 aerial photographs and the patterns could be recognized on the ground during the 2003 field trip. Large termitaria were digitized on a portion of the 1943 photo mosaic and overlaid in a GIS with existing farms in 1943 and a map of the oshanas. The result is presented in Fig. 13. Few termitaria were mapped in or just next to Oshanas and a lower number were also mapped on central areas between Oshanas, consisting mainly of Omufitu. Most farms have termitaria and many have a large number. Since the area still had much unsettled land available in 1943, there are areas with high concentrations of termitaria that are not settled. Three farmers in the survey in Ondobe responded that their parents settled the farm area because of the abundance of termites, while also Hillyer (*pers. comm.*) found in interviews with over 20 farmers that the presence of termites was a factor in establishing their fields. In 1992 the area was virtually fully settled with a pattern similar to Area 7 (Omatunda). The distribution of termitaria in the same area as in Fig. 13 is presented in Fig. 14. A visual comparison suggests that in 1992 termitaria were more common in sandy areas than in 1943.

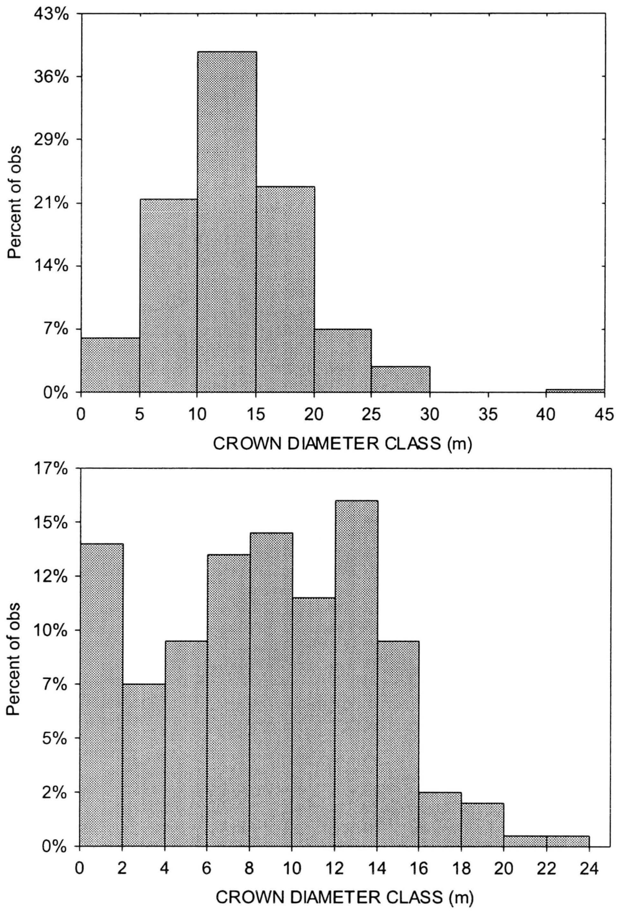

Fig. 8. Above: Crown diameter distribution of *Sclerocarya birrea* measured on 20 farms in Ondobe area in January 2003 ($N = 280$). Mean crown diameter is 13.1 m. Ages of farms not all known but most were settled long before 1970. Below: Crown diameter distribution of *Sclerocarya birrea* measured on 23 farms in Okahao area in December 2002 ($N = 140$). Ages of farms not all known but many were settled after 1960.

4. Discussion

This study suggests that local settlement patterns are best understood by taking indigenous environmental knowledge with its recognition of a local land classification system as the basis for land use mapping. While previous analyses of settlement in the area pointed to the importance of soil fertility, elevation and availability of surface water (Marsh and Seely, 1992; Mendelsohn et al., 2000; Erkkilä, 2001), settlement decisions seem to be more complicated in many areas. In the least fertile Kalahari Sandveld, settlement is indeed concentrated around temporary surface water and more fertile soils found around pans (Mendelsohn et al., 2000). Elevation is not important as especially in the central Cuvelai area, early settlers selected areas with high diversity in gradients and hence high

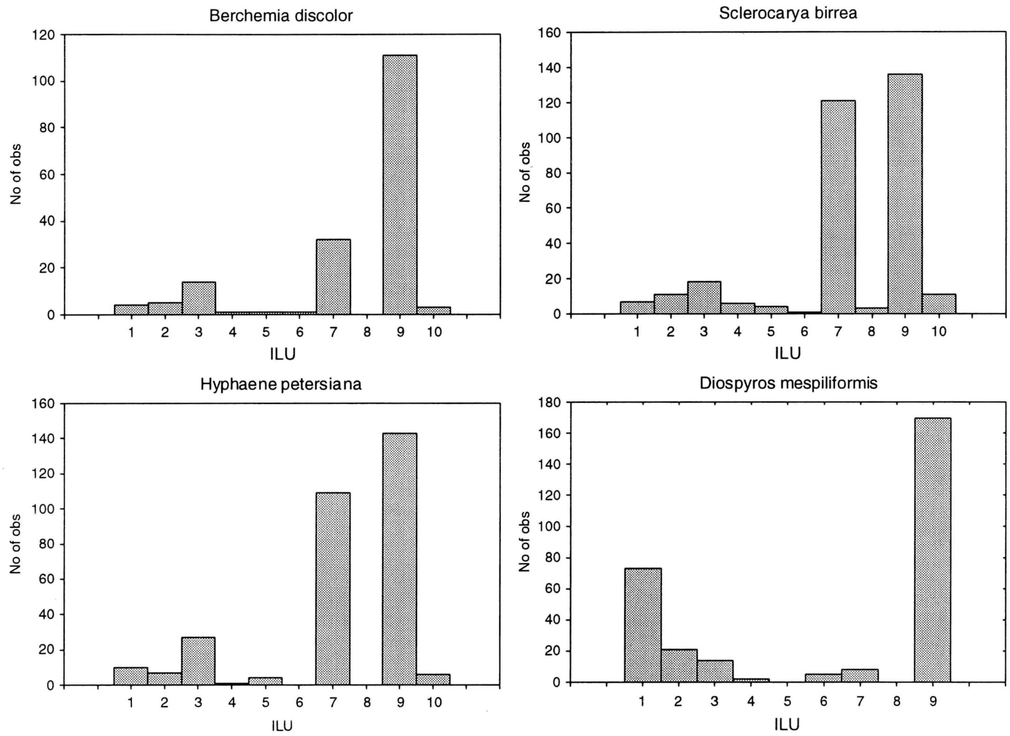

Fig. 9. Number of observations of the four most abundant indigenous fruit tree species in the Ondobe area. Trees were measured on farm and farm area was divided between Indigenous Land Units (ILUs). 1: Ediwa, 2: Ehenene, 3: Ehenge, 4: Ehengefitu, 5: Elondo, 6: Iitunu, 7: Omufitu, 8: Omufitu-Elondo, 9: Omutunda, 10: Omutunda-henge.

diversity in ILUs, resulting in a pattern of elongated farms encompassing dune tops down to floodplains, initially avoiding the least fertile or most waterlogged areas.

This study found a good agreement between independently mapped ILUs, farm boundaries and statements of local people on constraints and potentials of ILUs for utilization and management of various resources, a clear case of a high level precision farming (Osbahr and Allen, 2003). The case studies also suggest that increased population levels seem to force people to settle or expand farms on land that is less diverse and contains more unsuitable areas for a variety of crops. But this only happens when these less fertile ILUs are close to more fertile ILUs, close to water and in a diverse landscape. When those conditions are not met, attempts to settle on less fertile ILUs fail. The study of Dayot and Verlinden (1999) in the Eastern Kalahari Sandveld reported that livestock requires access to more fertile ILUs. If they are not available, parts of the herd have to be sent away, taken care of by relatives or other people. This results in insufficient manure being produced on farm. The data also showed, contrary to expectation, that when more fertile ILUs are abundant, occupation of these ILUs is relatively small except at very high human population densities. An increase in the level of occupation is found in the least fertile ILUs of the most densely populated areas. The maximum percentage of occupation of the

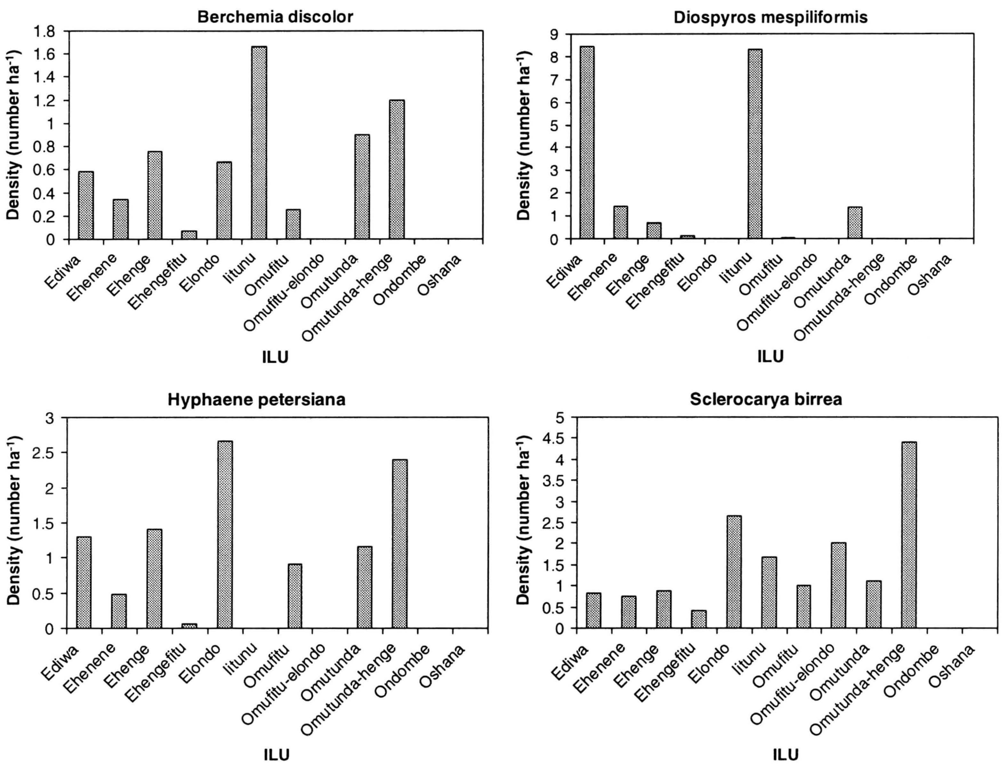

Fig. 10. Density (number of trees ha^{-1}) of the four most common indigenous fruit trees on different ILUs in Ondobe.

most preferred ILUs is only 80%. That the most preferred ILUs are not completely settled even at very high population levels points to the importance of diversity. The central portion of a large area of uniform Omutunda is less likely to be settled than at the edges where there is a larger variety of ILUs, even when there is abundant water supply. Hillyer (2004) reports that farmers select less fertile ILUs for cropping legumes especially Bambara Groundnuts (*Vigna subterranea* L.) and Groundnuts (*Arachis Hypogaea* L.) while the adjacent more fertile ILUs are used primarily for cropping millet (*Pennisetum glaucum* (L.) R. Br.).

The trade-off between livestock rearing and cropping can be analysed with ILU classifications. The data suggest that when more than 70% of the more fertile ILUs are enclosed, people without cattle posts cannot keep sufficient numbers of livestock for their needs. Interviews combined with GIS analysis suggests that when proportions of more fertile ILUs are lower than 30% and enclosure of these more than 30%, some people decide to move elsewhere with their livestock to start new farms, even if the overall enclosure of land is only 15%.

The published habit of moving homesteads and kraals around in farms (Erkkilä, 2001) is still thought to be a main factor in maintaining soil fertility and in the protection of fruit trees. Except in a few cases, a clear pattern of groves of *Sclerocarya birrea* the size of a

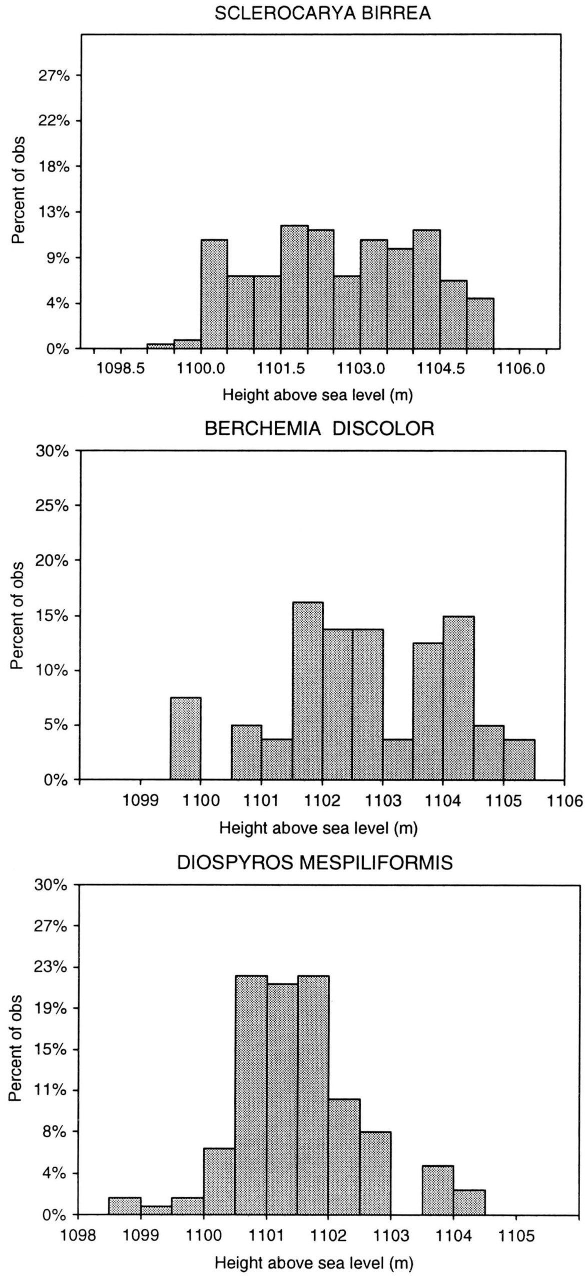

Fig. 11. Distribution of measured common indigenous fruit trees along the elevation gradient in the southern portion of Ondobe area.

homestead as mentioned by (Botelle et al., 2002) was not found. Homestead rotations in areas near urban centres with very high population densities are thought to be insufficient for maintaining soil fertility. This is probably due to a lack of manure which is reported to

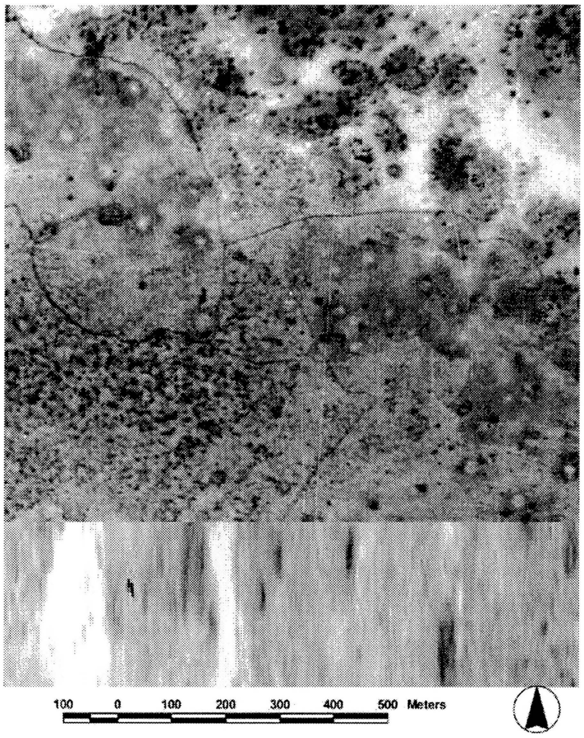

Fig. 12. Some people claimed to select sites with a high termite activity for farming. The white circles with a surrounding darker ring indicate large termite mounds. Although such mounds also occur outside the cleared field area, this portion of a 1943 aerial photograph composite suggests that the vast majority of termite mounds in this short Mopane shrub area are found in the cleared fields.

be a chronic problem in such areas (Marsh and Seely, 1992). A typical ILU associated with frequent homestead and kraal rotation in combination with application of manure called Etathapya was not reported for such areas, although it was quite common in less densely populated areas with more grazing land available.

Researchers in the study area have stated that when new lands were opened for cultivation, the bulk of woody vegetation was removed, but desirable indigenous fruit trees were left standing (Koivu, 1925; Siiskonen, 1990; Marsh, 1994; Erkkilä, 2001). This study found that certain fruit tree species, including those that are currently most abundant, were not present at all when the Okalongo area was settled. Natural vegetation with *Sclerocarya birrea* in Namibia and Southern Africa always contain large trees. This is the case for fruit trees with a large canopy like *Berchemia discolor* and *Sclerocarya birrea*. Other species like *Diospyros mespiliformis* and *Hyphaene petersiana* were likely to be present in the area before settlement, but their distribution differs from that outside settled areas. The occurrence of *Diospyros mespiliformis* on Omutunda found only within farm boundaries differs from their expected affinity for wet areas, while the occurrence of *Hyphaene petersiana* on the very sandy Omufitu found only on farms differs from their expected affinity for shallow or seasonally wet soils outside farms. Field data in Botelle et al. (2002)

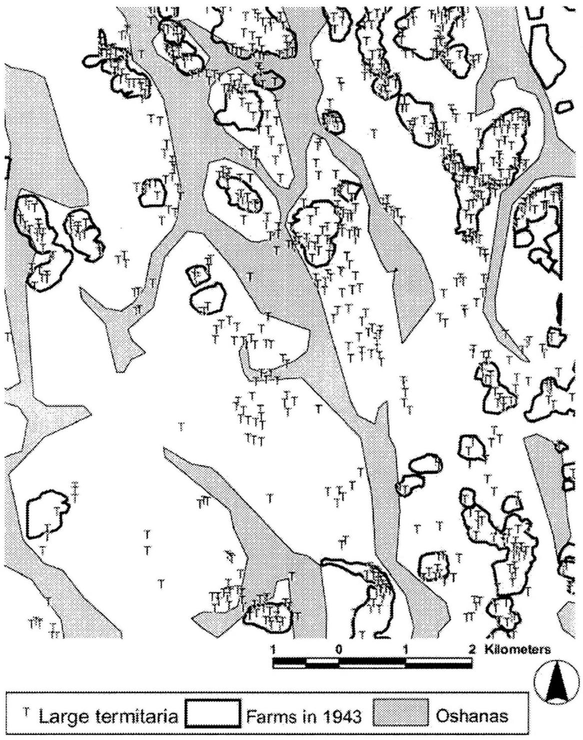

Fig. 13. Distribution of large termite mounds mapped on a portion of the 1943 aerial photo mosaic, overlaid with a map of the Oshanas and the established farms in 1943.

and this study confirm that *Berchemia discolor* and *Sclerocarya birrea* are very rare outside fenced farm areas. Those that were observed were the result of farms being abandoned due to road building on their land.

Only about half of the farmers interviewed in this study allowed their livestock to browse trees on their farm, suggesting that livestock on many farms are prevented from grazing and browsing (SDP 11, 2003). Botelle et al. (2002) argue that most browsing occurs during the dry season after harvesting, when most fruit trees have lost their leaves and are dormant. In Ondobe, the density of the four most common fruit trees found on farm amounts to more than 3 ha^{-1}.The majority of these are on fields that are regularly plowed. The diameter distribution of all studied fruit trees suggest that continuous regeneration is allowed, although care is often limited and male trees may be destroyed. The selection in favor of fruit bearing individuals is much higher in Okahao, possibly the result of wood shortage in that area. Lopping of branches of male *Sclerocarya birrea* for livestock fodder was observed more often there than in Ondobe.

The interpretation of the historical aerial photographs confirms the notion of most people interviewed in this study and is consistent with those interviewed by Botelle et al. (2002) and den Adel (2002), that many fruit trees were not present when the farms were established. The data also confirm the opinion of 90% of the farmers interviewed that currently, the common fruit trees and especially *Sclerocarya birrea* and *Berchemia discolor*

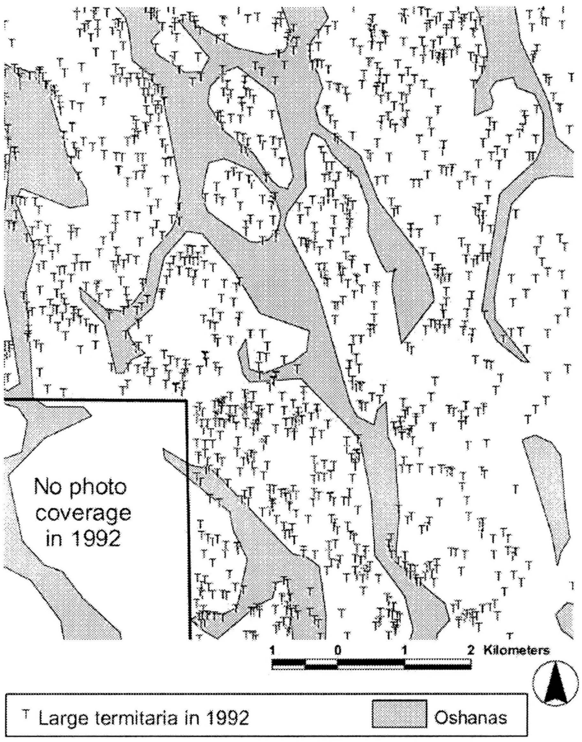

Fig. 14. Distribution of large termite mounds mapped on a portion of the 1992 aerial photo mosaic, covering the same area as Fig. 13, overlaid with a map of the Oshanas. Virtually the whole area was settled in 1992, except the Oshanas.

have increased over time and are still increasing. The different crown diameter distributions confirm the observation on the aerial photographs that in Okalongo area, indigenous fruit trees with a large canopy were not present before settlement. In the Okahao area, recently established farms still have no indigenous fruit trees. Elderly farmers said they brought fruits from areas where they were well established but stressed that most trees were established through casual seed dispersal, although fruit trees might be protected after establishment. Interviews in this study (over 200) and the published records of interviews in various other villages (Botelle et al., 2002; den Adel, 2002; SDP 11, 2003) show that aftercare (watering, protection, fertilizing) is limited to around 10% of farmers. It could be argued that in the 1940s only small *Sclerocarya birrea* were present as competition or browsing may have limited their growth. Yet the area was hardly settled then and the numbers of livestock present were limited, especially since goats as the main browsers rarely venture further than 2 km from a homestead (Verlinden et al., 1998). The aerial photos show that the Mopane shrub vegetation in Okalongo was not dense, hence competition was unlikely to prevent growth from *Sclerocarya birrea* and *Berchemia discolor*. The lack of mature trees of *Sclerocarya birrea* in Southern Africa is associated with high elephant impact (Eckhardt et al., 2000; Jacobs and Biggs, 2002) and elephant population levels were very low throughout the 20th century in northern Namibia.

Establishment of trees on farm as a result of management is not limited to fruit trees on fields. In the Okalongo historical study area a few cases of established live fences were found. Shitundeni and Marsh (1999) suggest that most of these live fences have a similar origin as the indigenous fruit trees: casual seed dispersal in protected areas. In this case, brush fences form the main protection. The relative short life-span of a brush fence might explain why live fences are not more widespread. In some areas where live fences are widespread (Shitundeni and Marsh, 1999), *Combretum imberbe* is the main live fence species, a species that in its young stage is well protected against browsing and serves the purpose of preventing livestock from entering farms quite well.

5. Conclusions

The resulting picture of settlement strategies in Central North Namibia is that farmers settle areas, not based on elevation, but based on an indigenous land classification that is holistic and based not only on soil fertility, but also on drainage properties, plant indicator species, termite activity, micro relief and landform. People do not select primarily the most fertile ILUs, they have to be close to water and, notably, part of a more diverse landscape with several ILUs over a distance of a few hundred meters. People emphasized hydrological properties of different ILUs especially with reference to the depth of a hard pan. It is suggested that having a wide range of ILUs responding differently to a range of rainfall scenarios is advantageous in semi-arid areas with a high variability in rainfall (Hillyer, 2004). Having only one preferred ILU like Omutunda on farm might be advantageous in most scenarios, but not during droughts or very high rainfall. This suggests a trade-off between choosing Omutunda only or including other ILUs who perform best during droughts (Omufitu in the Cuvelai basin) or during very high rainfall (Ehenge). This might result in a reduced harvest in 'good' rainfall years, but a more sustained harvest in the long run.

Combinations of several ILUs are not only required for cropping, they are also required for livestock. In all areas, people stressed that for successful livestock rearing and cropping combinations, land had become too scarce. This study emphasizes that the ratio between enclosed and unenclosed land is less important than the ratios between more fertile ILUs and less fertile ILUs and the degree of enclosure of more fertile ILUs.

The trade-off is that both livestock and cropping require the more fertile ILUs and when more fertile ILUs are enclosed, less livestock can be kept, even at enclosure rates of less than 15%. The trade-off can occur at low settlement densities when the majority of the area consists of less fertile ILUs.

This study confirm the oral history that people do not select areas because of the presence of preferred fruit trees as they are mostly lacking in newly settled areas. Some management practices like fencing farms with *Acacia* spp. as protection from livestock during certain times of the year and building homesteads with *Colophospermum mopane* and *Terminalia sericea* causes deforestation, by clearing land for fields and using the cut trees for fencing and construction. The fencing practices increase the survival rate of mostly casually sown and rarely planted fruit trees.

Homestead and kraal rotation increases soil fertility, supplementing the enrichment of the topsoil by termites. The practice also encourages the establishment and survival of fruit trees. There is some evidence that kraal and homestead rotation is partly induced by increased termite activity on farms, possibly as a result of the lack of dead wood in the surrounding area and the large amount of woody biomass used in homestead construction on very sandy ILUs that reportedly sustained less termites originally. This suggests a trade-off between selecting areas with termites for soil fertility and homestead longevity. Building homesteads in ILUs with less termites seems only a short term solution. The data presented here also suggest that old termitaria are associated with a higher abundance of some fruit trees. (Kreike, 1995) mentions a practice whereby soil from old termite mounds is spread over fields to increase fertility. Soil from termitaria is also used in homestead construction. Over time, as a result of homestead rotation, such practices are likely to improve soil properties over a larger area. The interactions between termites, homestead rotation and soil fertility require more research.

With respect to cropping and livestock rearing, the amount and spatial distribution of the most fertile land units is critical, after the availability of water, to the livelihood and settlement strategies of local people. This paper shows that the study of indigenous land classifications are a good basis to understand these strategies and the local trade-offs between grazing and cropping, homestead location and termite activity. These conclusions are important with respect to recommendations for improved resource management, land reform, grazing and resettlement schemes.

While certain indigenous farming practices have been shown to cause deforestation and environmental degradation, other indigenous practices have the opposite effect. This study confirms earlier suggestions based on oral history that the current fruit tree landscape in the central Cuvelai drainage system of Central North Namibia is a result of indigenous management practices encouraging the dispersal and establishment of multipurpose trees that have important economic properties and cultural aspects.

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References

Botelle, A., du Plessis, P., Pate, K., Laamanen, R., 2002. A Survey of Marula Fruit Yields in North-Central Namibia. CRIAA SA-DC, Windhoek 26pp.

Brown, C.J., 1992. Namibia's Green Plan to Ensure for Present and Future Generation a Safe and Healthy Environment and a Prosperous Country. Ministry of Wildlife, Conservation and Tourism, Windhoek 174pp.

Chambers, R., 1994. The origins and practice of participatory rural appraisal. World Development 22, 953–969.

Coates-Palgrave, K., 2002. Trees of Southern Africa. Cape Town, Struik.

Dayot, B., Verlinden, A., 1999. Indigenous knowledge systems on integrated resource use: local land classification and resource management in North Central Division. In: Republic of Namibia, M.o.A., Water and Rural Development. (Eds.), Proceedings of the Annual Conference on Agricultural Research. Swakopmund, Namibia 6–10 September 1999, 254pp.

den Adel, S., 2002. Use of Marula Products for Domestic and Commercial Purposes by Households in North-Central Namibia. CRIAA SA-DC, Windhoek 38pp.

Eckhardt, H.C., Van Wilgen, B.W., BIGGS, H.C., 2000. Trends in woody vegetation cover in the Kruger National Park, South Africa, between 1940 and 1998. African Journal of Ecology 38, 108–116.

EDG, 1996. Northern Namibia Environmental Project, Namibia. General and Technical Proposal to ODA. Environment and Development Group, Oxford, UK 64pp.

Erkkilä, A., 2001. Living on the land: change in forest cover in north central Namibia 1943–1996. Silva Carelica 37, 118.

Erkkilä, A., Siiskonen, H., 1992. Forestry in Namibia 1850–1990. Silva Carelica 20, 1–245.

Hillyer, A.E.M., 2004. Room to Grow: Local Knowledge, Land Use and Legumes in the Farming Systems of Northern Namibia. Thesis of the University of East Anglia, Norwich, UK.

Hutchinson, P., 1995. The climatology of Namibia and its relevance to the drought situation. In: Moorsom, R. (Eds.), Coping with Aridity: Drought Impacts and Preparedness in Namibia—experiences from 1992/93. Prepared for the Ministry of Agriculture, Water and Rural Development and UNEP. Brandes & Apsel Verlag GmbH, Frankfurt, Windhoek, pp. 17–37.

Jacobs, O.S., Biggs, R., 2002. The status and population structure of Marula in the Kruger National Park. South African Journal of Wildlife Research 32, 1–12.

Koivu, K., 1925. Amboneekerin jokopaivanen leipa: kuvauksia ja mietteia ambokansan taloudeliisista oloista. Suomen Laheetiseura, Helsinki 194pp.

Kreike, E.H.P.M., 1995. The Ovambo Agro-Silvipastoral System, Traditional Land Use and Indigenous Natural Resource Management in North Central Namibia. Forestry Publication 4, Directorate of Forestry, Windhoek, Namibia, 36pp.

Lechevallier, M., Weill, E., 2001. A diagnosis of farming systems in Omuthiya Consituency, Oshikoto region, North Central Namibia. CNEARC National Centre for Study on Tropical Agronomy, Montpellier, France, 120pp.

Marsh, A., 1994. Trees: Threatened Lifeline of Northern Namibia: The People's Perspective. Gamsberg Macmillan, Windhoek 72pp.

Marsh, A.C., Seely, M.K., 1992. Oshanas: Sustaining People, Environment and Development in Central Owambo, Namibia. Desert Research Foundation and SIDA, Windhoek 54pp.

Matanyaire, C.M., 1995. The combined effects of aridity and drought on agriculture. In: Moorsom, R. (Ed.), Coping with Aridity: Drought Impacts and Preparedness in Namibia—Experiences from 1992/93. Prepared for the Ministry of Agriculture, Water and Rural Development and UNEP. Brandes & Apsel Verlag GmbH, Frankfurt, Windhoek pp. 105–123.

McDonagh, J.F., Hillyer, A.E.M., 2001. PSP Project, Project R 7069. Increasing pearl millet production through improved use of grain legumes and animal manures. Final Technical Report. Overseas Development Group. University of East Anglia, Norwich, UK, 34pp.

Mendelsohn, J., El-Obeid, S., Roberts, C., 2000. A profile of North Central Namibia. Gamsberg Macmillan, Windhoek, Namibia 79pp.

Nott, C., Verlinden, A., Kuushomwa, L., Kazapua, V., 2003. Participatory Natural Resource Information Systems for Community-Based Natural Resource Management. NRSC and Rössing Foundation, Windhoek, Namibia 110pp.

Osbahr, H., Allen, C., 2003. Indigenous knowledge of soil fertility management in southwest Niger. Geoderma 11, 457–479.

Rigourd, C., Sappe, T., 1999. Investigating into soil fertility in the North Central Region. In: Kaumbutho, P.G., Simalenga, T.E. (Eds.), Conservation Tillage with Animal Traction. Rundu, Namibia, pp. 34–42.

Rigourd, C., Sappe, T., Talavara, P., 1999. Soil fertility and minimum tillage equipment trials in the North Central, Namibia. In: Kaumbutho, P.G., Simalenga, T.E. (Eds.), Conservation Tillage and Animal Traction. Rundu, Namibia, pp. 115–119.

SDP 11, 2003. The role of indigenous fruit trees in farming sytems in North Central Region, Namibia. Summer Desertification Programme 11. Desert Research Foundation of Namibia, Gobabeb, 57pp.

Shitundeni, J., Marsh, A., 1999. Indigenous Soil Classification and its Possible Relevance to Forestry Extension in Central North Namibia. CFEDP, Ongwediva, Namibia 30pp.

Siiskonen, H., 1990. Trade and socioeconomic change in Ovamboland 1850–1906. Studia Historica 35, 269.

Thomas, D.S.G., Shaw, P.A., 1991. The Kalahari Environment. Cambridge University Press, Cambridge 284pp.

Turner, M.D., Hiernaux, P., 2002. The use of herders' accounts to map livestock activities across agropastoral landscapes in Semi-Arid Africa. Landscape Ecology 17, 367–385.

van der Waal, B.C.W., 1991. Fish life of the Oshana Delta in Owambo, Namibia, and the translocation of Cunene species. Madoqua 17, 201–209.
Verlinden, A., Dayot, B., 2000. Working with local knowledge systems in a GIS for natural resource assessment, planning and management in North Central Namibia. In: Caron, P., Swanepoel, F., Stroebel, A. (Eds.), Proceedings of the Regional Workshop on Spatial Approaches for Land use and Local Governance. University of Pretoria, post-graduate school of Agriculture and development, pp. 63–78.
Verlinden, A., Dayot, B., 2005. A comparison between indigenous environmental knowledge and a conventional vegetation analysis in north central Namibia. Journal of Arid Environments 62, 143–175.
Verlinden, A., Perkins, J.S., Murray, M., Masunga, G., 1998. How are people affecting the distribution of less migratory wildlife in the southern Kalahari of Botswana? A spatial analysis. Journal of Arid Environments 38, 129–141.
Verlinden, A., Munyenyembe, J.K.K., Jambo, P., Patel, I.H., 2003. We still need the trees. Consultancy on Land-Use Classification Methodology Based on Existing Indigenous Knowledge. The Sustainable Forest Management Programme, Mzuzu, Malawi, pp. 1–70.