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Vegetation of the central Kavango woodlands in Namibia: An example from the Mile 46 Livestock Development Centre

B.J. Strohbach ^{a,*}, A. Petersen ^b

^a National Botanical Research Institute, Private Bag 13184, Windhoek, Namibia

^b Institute for Soil Science, University of Hamburg, Allende-Platz 2, 20146 Hamburg, Germany

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Abstract

No detailed vegetation descriptions are available for the Kavango woodlands — recent descriptions have all been at the broad landscape level without describing any vegetation communities. With this paper the vegetation associations found at and around the Mile 46 Livestock Development Centre (LDC) are described. Two broad classes are recognised: the Acacietaea are represented by three *Acacia* species-dominated associations on nutrient-rich eutric Arenosols, whilst the Burkeo–Pterocarpetea are represented by three associations dominated by broad-leaved phanerophytic species on dystri-ferralic Arenosols. The, for the Kavango woodlands typical, *Pterocarpus angolensis*–*Guibourtia coleosperma* bushlands and thickets are further divided into four variants. Fire has been found to be an important factor in determining the structure of the vegetation — exclusion of fire on the LDC itself seems to lead to an increase in shrub (understorey) density.

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Keywords: Arenosols; Fire; Kavango woodlands; Land-use impact; Namibia; Zambesian Baikiaea woodlands ecoregion

1. Introduction

Very few phytosociological studies have been undertaken in the past in Namibia (Burke and Strohbach, 2000; Strohbach, 2001). This, linked with a similar situation regarding soil surveying, essentially means there is a lack of baseline data for land-use planning. With increasing demands for land, proper land-use planning becomes an urgent need of national importance. With this in mind, a project was launched to map and properly describe the vegetation of Namibia in the late 1990s (Strohbach, 2001).

Baseline information on the vegetation of the Kavango Region is as limited. An early description by Page (1980) was based on Forestry Resource maps, whilst later descriptions by De Sousa Correia and Bredenkamp (1986) and Burke (2002) describe the vegetation only in broad, reconnaissance-level

terms. Yet pressure on the land is increasing — Mendelsohn and el Obeid (2003) illustrate this very clearly in their profile on the Kavango Region. Whereas in 1943, only 26,140 ha of land had been cleared for crops along the Kavango River terrace, this increased to 72,100 ha in 1972, following main river beds into the hinterland, and to 194,550 ha in 1996, following all available access routes into the hinterland in the search of productive soils. This amounts to an average increase in cropped fields of 3.9% per year.

The rural population not only uses land for cropping, but is highly dependant on vegetation resources for their livelihoods. Cattle are grazed; timber is harvested for construction purposes as well as carvings; thatch-grass is harvested; and numerous other resources are used from the wild (Geldenhuis, 1996). These land-use pressures are exacerbated by frequent fires. It is estimated that between 30 and 50% of the total area of the Kavango Region is burned annually from anthropogenic causes (De Sousa Correia and Bredenkamp, 1986; Mendelsohn and el Obeid, 2003). These frequent fires are regarded as one of the main causes of vegetation change in the region (Burke, 2002).

* Corresponding author.

E-mail address: bens@nbri.org.na (B.J. Strohbach).

(De Pauw et al., 1998/99). As part of the BIOTA project, an automated weather station was erected at the LDC. Using the available data (3 years), a climate diagram following Leith et al. (1999) was constructed, as well as a wind rose depicting the dominant wind directions during the year (Fig. 2). It should be noted that the rainfall during these measured years was below average, possibly also resulting in above average high temperatures.

2.3. Topography, geology and soils

The study area falls within the extensive Kalahari sand basin. These aeolian sands were finally deposited ca. 30,000 years ago as longitudinal, east–west orientated dunes (Hegenberger, 1986). Through erosion, the topography at the study area was flattened to less than 10 m relative difference in relief, although the remnants of the dune fields are still clearly visible in satellite images (Graz, 1999). The depth of the sand cover is estimated to be between 20 and 40 m, although the entire Kalahari sequence is approximately 150 m deep (Hegenberger, 1986; Geological Survey, 1980). The Mile 46 LDC is crossed by the upper Mpuku Omuramba, which incises deeply into the sand plateau (Graz, 1999; De Sousa Correia and Bredenkamp, 1986). Soil information on the broader study area is provided by the FAO soil map (1997) and the Agro-Ecological Zoning Programme of the Ministry of Agriculture, Water and Forestry (AEZ) (NARIS, 2001). The area is dominated by cambic Arenosols, albic Arenosols, calcic Xerosols (FAO, 1997, revised legend). The AEZ (NARIS), following the World Reference Base for Soil Resources (FAO, 1998), indicates ferralic Arenosols as dominant soil units with associated petric Calcisols. Both

sources only inventorise the soil units without regionalising these.

Typically, the soils are deep, very pure sands with little nutrients. Heavier textured soils have formed only in the *omiramba* (singular – omuramba – a wide, flat watercourse with no visible gradient — King, 1963). A number of these omiramba cross the study area in an east–west direction, contributing to the Mpuku Omuramba. These omiramba, because of their more nutrient-rich soils, are sought-after for fields by the local population (Graz, 1999; Burke, 2002).

2.4. Vegetation

The Kavango falls within the Zambesian *Baikiaea* woodlands ecoregion as delimited by the World Wildlife Fund (WWF) (Vetter, 2001a). As such, it is dominated by open woodlands with numerous hardwood species, including *Baikiaea plurijuga*, *Pterocarpus angolensis* and *Guibourtia coleosperma*. Although named after *Baikiaea plurijuga*, it is pointed out in the WWF description (Vetter, 2001a) that this species is fire-sensitive and used extensively for timber, thus becoming rare. Giess (1998) includes the study area in the Northern Kalahari Woodland savanna.

De Sousa Correia and Bredenkamp (1986) described a series of land-use units within the Kavango Region, mostly being dependant on the depth of the sands. According to their classification, the study area falls within the C2 land-use unit, described as flat to slightly undulating plains covered by an open *Burkea africana* tree or shrub savanna. According to these authors, *Baikiaea plurijuga* and *Schinziophyton rautanenii* are usually absent. Shallower soils occur in depressions; these are then dominated by *Terminalia sericea*,

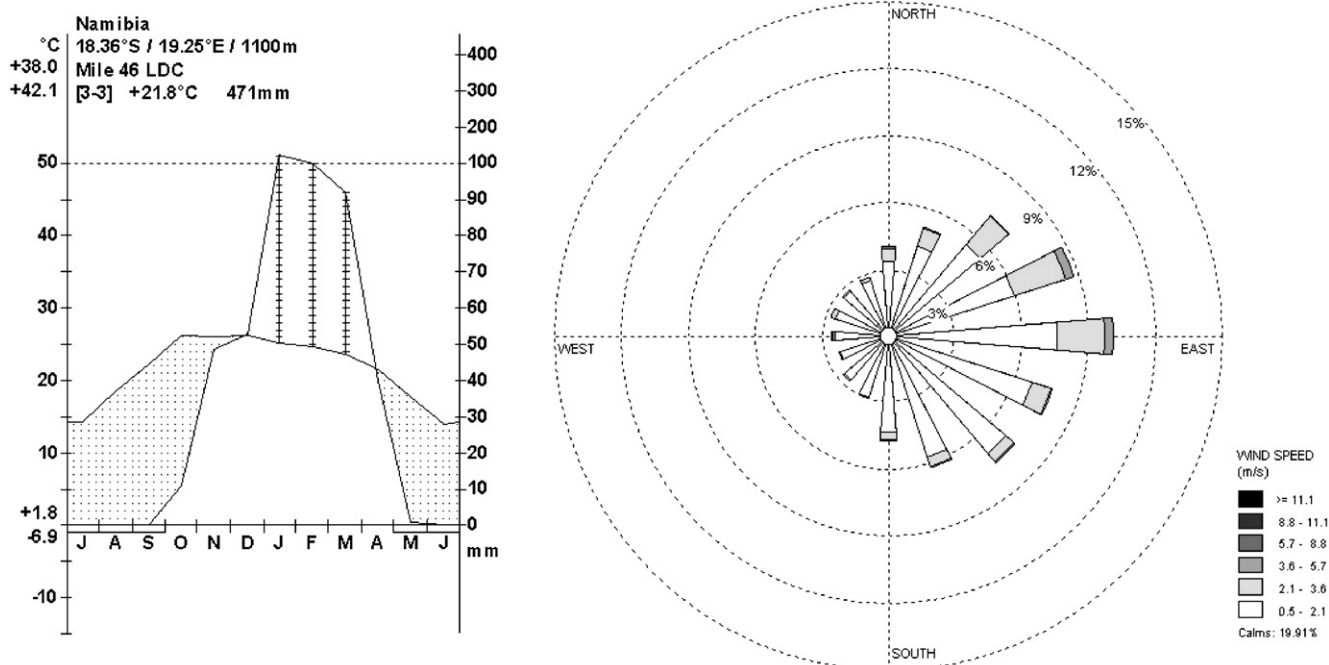


Fig. 2. Left: climate diagram following Leith et al. (1999). Right: windrose of the average wind directions and speeds during the entire year.

Burkea africana, *Lonchocarpus nelsii*, *Combretum imberbe* and *Acacia erioloba*. They describe the herb layer as usually *Dichapetalum*-free. Their view that the depth of the sands is determinant for the composition of the woodlands is shared by Geldenhuys (1977).

Burke (2002) includes the study area in her Northern sandplain, which is dominated by *Pterocarpus angolensis* and *Schinziophyton rautanenii* woodlands, as well as isolated patches of *Baikiaea plurijuga* and *Burkea africana* woodlands. Throughout, *Combretum collinum* is an important component of the tree layer, whilst *Combretum zeyheri*, *Combretum psidioides*, *Bauhinia petersiana* and *Baphia massaiensis* are prominent shrub components. *Digitaria seriata*, *Schmidtia pappophoroides* and *Urochloa brachyura* are common grasses associated with these woodlands. She points out that the omiramba here are heavily transformed by human land-use and form a mosaic of cultivated fields, dense shrub regrowth on old fields, as well as occasional *Acacia erioloba* shrublands. According to Burke (2002), the present vegetation is heavily influenced by human activities, especially burning, which is transforming large parts of the landscapes. Geldenhuys (1977) points out that regular fires are part of the ecosystem, and that, with an exception of a few fire-sensitive species like *Baikiaea plurijuga*, *Guibourtia coleosperma* and *Ochna pulchra*, most are adapted to frequent fires. He concludes that fires are an important factor keeping the woodland understory open, without which dense thickets would form.

2.5. Field surveys

Using a false colour satellite image (Landsat 7ETM, Path177 Row 73 dated 24 April 2000, Bands 451 RGB) as base map of the area, 153 surveys were done during February and March 2003 along the main paths and tracks in and around Mile 46 LDC as well as at the two observatories, covering all visible colour and structural shadings on the image map. The surveys consisted of the compilation of relevés of 50 × 20 m plots at a given location. Unknown species were collected and pressed for later identification at the National Herbarium of Namibia (WIND). These specimens were also deposited there. This floristic survey included a growth form classification after Edwards (1983) as well as an abundance estimate (% crown cover). This was augmented by a habitat description, including the latitude and longitude determined with a Garmin GPS 12XL, landscape and topography description, slope and aspect (if the slope was any steeper than “undulating” or 6%), lithology and disturbances. No stones were found, so all stone cover ratings were zero. The habitat description follows the basic standard of Strohbach (2001). Ratings in all cases follow the FAO SOTER standards (FAO, 1993).

A total of 30 soil profiles of 2 m depths and 20 additional topsoils were documented and sampled at the two observatories (following FAO, 1990). Soil units were classified according to the World Reference Base for Soil Resources (FAO, 1998). Soil samples were air-dried and sieved to <2 mm. To investigate the physico-chemical factors the following analyses were undertaken following Van Reeuwijk (1995): particle size distribution, pH in H₂O and CaCl₂, electric conductivity in a 1:2.5 solution (EC_{2.5}), inorganic carbon (Wösthoff), carbon and total nitrogen

content measured by CNS-rapid analysis (VarioMax CNS, Elementar, Hanau, Germany).

2.6. Data analysis

After identification of the specimens at the herbarium, the data were captured in the TurboVeg database (Hennekens and Schaminée, 2001). Using the growth form and abundance data, a structure class was determined following Edwards (1983) for each relevé as part of the habitat data. Using TWINSpan from the PC-Ord package (Hill, 1979; McCune and Mefford, 1997) as an initial mathematical classification procedure, the relevés were classified following standard Braun–Blanquet procedures (Mueller-Dombois and Ellenberg, 1974; Werger, 1974). In order to verify the classification results, the data were subjected to a reciprocal averaging (RA), also part of the PC-Ord package.

As part of the descriptors, averages of the tree, shrub and grass cover, as well as average numbers of species have been calculated.

2.7. Mapping

Landsat 7ETM image Path177 Row 73 (dated 24 April 2000), Bands 1–5 and 7, was used for the final mapping of the vegetation. eCognition Professional 4 (Definiens Imaging, 2004) was used to subdivide a subsection of the image between 18°11'52"S 19°11'33"E and 18°27'48"S 19°27'50"E into “segments” (homogenous areas) using a scale parameter setting of 20, shape factor of 0.3 (compactness and smoothness each 0.5) and the colour factor to 0.7. (As default the colour factor is 0.9 whilst the shape factor is only 0.1, subdivided in equal parts to compactness and smoothness.) Using the classified relevés as indication, sample segments were selected for each association, as well as cultivated fields. No attempt was made to map the variants of the *Pterocarpus angolensis*–*Guibourtia coleosperma* woodland association. The signatures (average colour values for the different bands) of the sample segments were compared, and a few doubtful sample segments were removed iteratively until a near-perfect classification result was obtained. The results were exported as a GeoTiff to IDRISI Kilimanjaro to calculate areas, as well as an ArcView shape file for final map production and for further use by the BIOTA and Agro-Ecological Zoning projects.

3. Results

Classification resulted in the relevés being grouped into two orders and six associations, one of which is subdivided into four variations. The classification results are depicted as phytosociological tables in Appendix A (excluding rare species, i.e. non-diagnostic species), whilst the ordination results are depicted in Figs. 3 and 4. The description of the syntaxa follows below. These resulting syntaxons are not formally described *sensu* Weber et al. (2000). The vegetation map is provided in Fig. 5. In addition to the acreages given in the description of the syntaxons below, cultivated fields covered 7458 ha in the study area (or 8.8%).

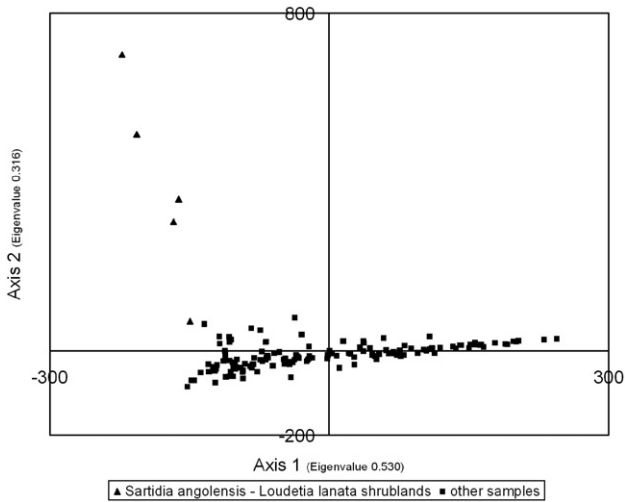


Fig. 3. Ordination diagram (reciprocal averaging) of all samples. The *Sartidia angolensis*–*Loudetia lanata* open shrublands dominate the second ordination axis similar to outliers.

3.1. The Acacietea

Volk and Leippert (1971) first mentioned the Acacietea as a syntaxonomic class, describing it as vegetation dominated by various *Acacia* trees and shrubs in central Namibia with outliers in Zimbabwe and Botswana. In this sense, this class is definitely present within the study area, being associated with the heavier soils of the drainage channels or omiribi. These are typical described as eutric Arenosols with a clay content of between 5 and 8%, forming a sand to loamy sand. The sand fraction has a mean quotient of 1.5 between medium to fine sand. pH varies

from slightly acidic to neutral. The depth of the soil is in most cases about 2 m or deeper. Mentionable amounts of organic carbon are found up to a depth of 70 cm. The Cation Exchange Capacity reaches from 30 to 45 mmol/kg (Fig. 6).

The Acacietea cover in total 10,021 ha or 11.8% of the study area. The three included associations are described below. A list of species occurring in these thickets, bush- and shrublands is presented by Strohbach and Strohbach (2004).

3.2. The *Acacia luederitzii*–*Croton gratissimus* thicket association

These closed to continuous thickets are dominated by *Acacia luederitzii* trees and shrubs, and are associated with various other thicket-forming phanerophytes, e.g. *Dichrostachys cinerea*, *Acacia mellifera* subsp. *detinens*, *Combretum here-roense*, *Mundulea sericea*, *Ochna cinnabarina*, *Croton gratissimus* and even *Acacia erioloba* trees. The average tree cover is 13%, shrub cover is 60%, whilst grasses amount to an average of 20%. The lianous *Hippocratea parvifolia* as well as numerous shade-loving plants, e.g. *Pupalia lappacea* and *Sporobolus fimbriatus* are also associated with this thicket. This grass species has been reported to be often associated with dense bush areas at Sonop Research Station, ca. 100 km to the south (Strohbach, 1992).

The *Acacia luederitzii*–*Croton gratissimus* thickets occur on loamy soils associated with drainage channels of the omiramba and cover about 6060 ha (7.1% of the study area). They have a fairly high species diversity, with an average of 54 species per 1000 m² (Fig. 8). This high diversity is due to the protection against grazing and fires offered by the dense woody layer, as

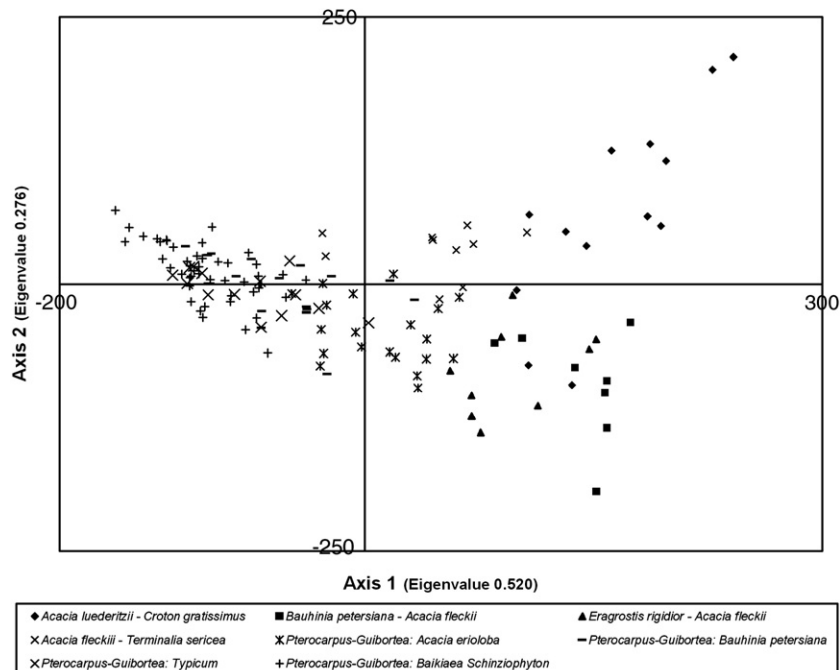


Fig. 4. Ordination diagram (reciprocal averaging) of all samples, excluding the *Sartidia angolensis*–*Loudetia lanata* open shrublands. Note the very continuous gradient, making especially the differentiation between the varieties of the *Pterocarpus angolensis*–*Guibourtia coleosperma* association difficult.

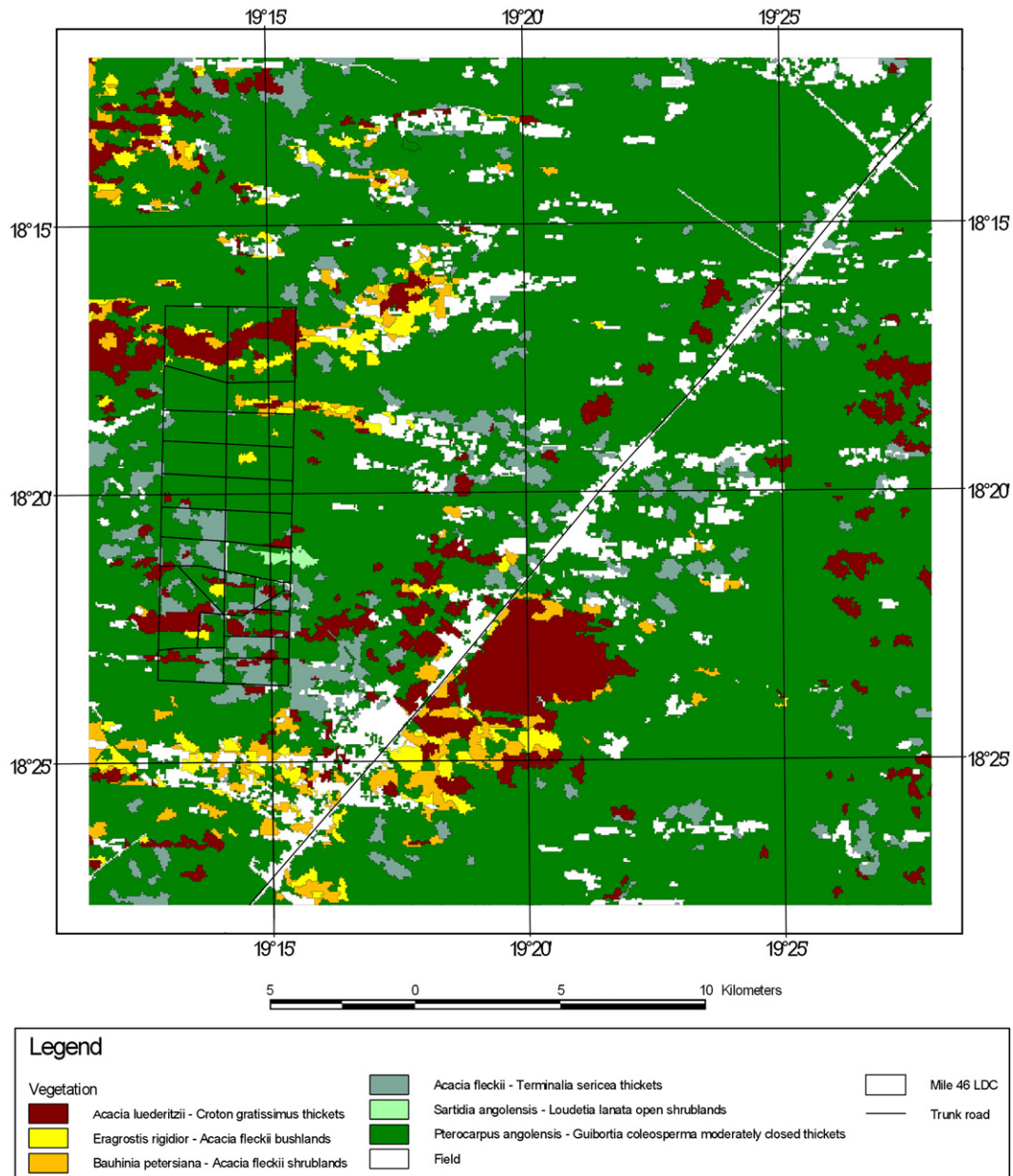


Fig. 5. Vegetation map of the study area.

well as the specialised niche habitats present in such dense vegetation associated with generally nutrient-richer, yet drier, soils. Because of the dense growth of woody species, however, this community is not an important grazing resource, mainly because of its in-penetrability.

3.3. The *Bauhinia petersiana*–*Acacia fleckii* shrubland association

These low to high (ca. 1–2 m) moderately closed to closed shrublands (occasionally even continuous shrublands) are characterised by the total absence of *Acacia luederitzii* trees, whereas *Bauhinia petersiana* subsp. *macrantha* occurs in great densities together with various other shrub-like phanerophytes like *Acacia fleckii*, *Dichrostachys cinerea*, *Helinus integrifolius*

and *Ximenia americana*. The tree cover is on average only 2%, whilst shrubs average 57% cover. A well-developed grass layer (average cover 21%) is dominated by *Eragrostis rigidior*, *Stipagrostis uniplumis*, *Schmidtia pappophoroides* and *Urochloa brachyura*. This association forms a transition between the thickets in the omiramba and the woodlands surrounding them, thus the high density of sand-loving shrub species. Occasional frosts, but especially fires, are thought to keep these shrublands in their relatively low structure. Species diversity is extremely high, with an average 63 species per 1000 m², occasionally even as many as 80 species per 1000 m² (Fig. 8). These shrublands as well as the following *Eragrostis rigidior*–*Acacia fleckii* bushlands are under threat by expanding fields for agronomic purposes. At present, this association covers 2248 ha or 2.6% of the study area.

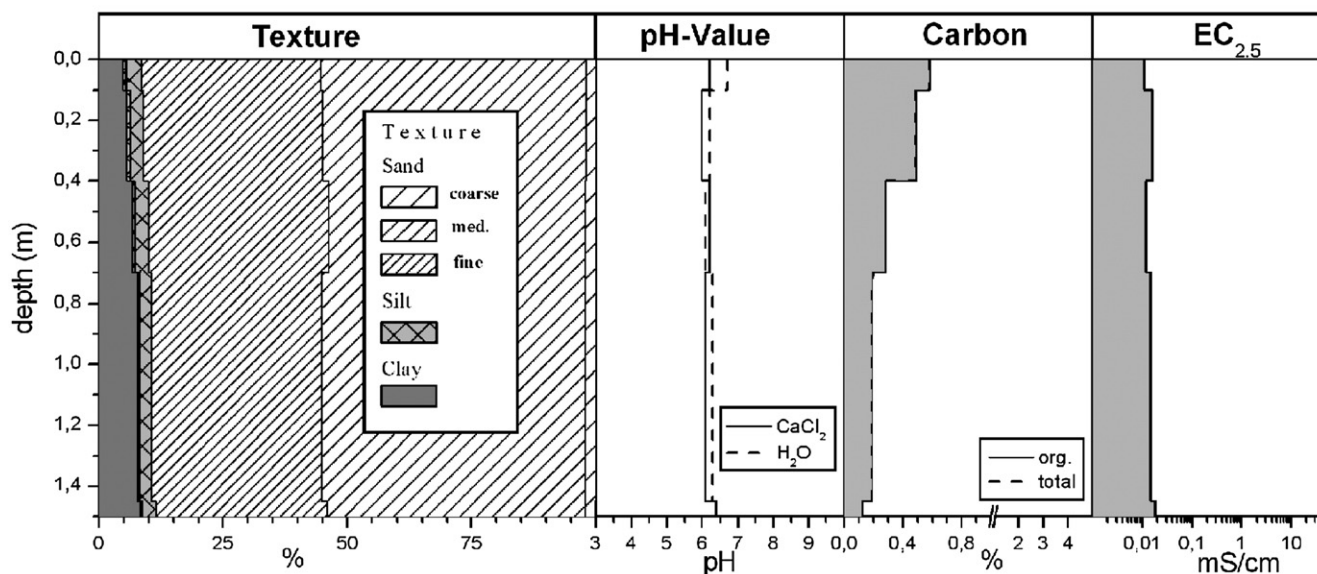


Fig. 6. Selected soil properties of a typical eutric Arenosol.

3.4. The *Eragrostis rigidior*–*Acacia fleckii* bushland association

The *Eragrostis rigidior*–*Acacia fleckii* bushlands form semi-open to moderately closed high bushlands, with 12 to 15 m high *Acacia erioloba* trees dominating the landscape (average tree cover 5%). In many respects it is very similar to the *Bauhinia petersiana*–*Acacia fleckii* shrublands, without however the near thicket-forming dense cover of *Bauhinia petersiana* subsp. *macrantha* shrubs (average shrub cover 40%). Without this dense shrub cover, the grass layer is free to develop, with valuable grazing grasses like *Schmidtia pappophoroides*, *Digitaria seriata*, *Urochloa brachyura* and, to a lesser extent, *Stipagrostis uniplumis* and *Brachiaria nigropedata* dominating this layer (average cover 28%). This association is not as diverse as the *Bauhinia petersiana*–*Acacia fleckii* shrublands, but still has an average of 55 species occurring per 1000 m² (Fig. 8). This association is also under threat of being cleared for fields, with only 1713 ha (or 2.0% of the study area) remaining intact. It is observed that most of the fields are made within this particular association. After clearing, however, many woody species and most herbaceous species survive in poorly maintained fields as coppice plants or ephemerals. Only the grass species diversity is drastically altered in favour of the crops.

3.5. The *Burkeo*–*Pterocarpetea*

Doubts exist regarding the naming of the Kavango woodlands as a vegetation class — according to the WWF, it is part of the Zambesian *Baikiaea* woodlands ecoregion (Vetter, 2001a), whilst both De Sousa Correia and Bredenkamp (1986) and Burke (2002) describe it as a *Burkea africana* woodland. As *Baikiaea plurijuga* occurs only in patches in these woodlands, but *Pterocarpus angolensis* is a widespread, well known species in these woodlands, it is suggested to name this vegetation class the *Burkeo*–*Pterocarpetea*. It is best described as an moderately closed to closed high woodland on deep Kalahari sands,

dominated by various Caesalpinioideae (*Burkea africana*, *Bauhinia petersiana*, occasionally *Baikiaea plurijuga* and *Guibourtia coleosperma*) and Papilionoideae (*Pterocarpus angolensis*), as well as Combretaceae (*Combretum* spp., *Terminalia sericea*). Being co-dominated by Caesalpinioideae, this class has affinities to the Miombo woodlands further north in Zambia and Angola. Subdivision of this order is debatable, as the WWF recognises a further ecoregion (~vegetative class?), the Kalahari *Acacia*–*Baikiaea* woodlands, south of the present study area (Spriggs, 2001). These woodlands cover 67,692 ha or 79.5% of the study area. A list of species occurring in these woodlands is presented by Strohbach and Strohbach (2004).

The soils are typically a dystric-ferralic Arenosol, consisting of deep (> 2 m) greyish to pale brown sand. The sand fraction has a mean quotient of 3 between medium to fine sand pH ranges from strongly to very strongly acidic, whilst the nutrient status of these soils is very low. Organic carbon is only mentionable in the topsoil (0–10 cm). The cation exchange capacity (CEC) is very low with 3–10 mmol/kg. Occasional patches of well developed black microbiotic crusts occur (Fig. 7).

3.6. The *Acacia fleckii*–*Terminalia sericea* shrubland and thicket association

The *Acacia fleckii*–*Terminalia sericea* association forms, for the *Burkeo*–*Pterocarpetea* atypical, dense (closed to continuous), tall shrublands (2–5 m) or low to short bushlands and thickets (2–6 m). Typically trees cover 9% of the area, whilst shrubs cover 60% of the area. This association is dominated by shrubs of the species *Terminalia sericea*, *Baphia massaiensis* subsp. *obovata*, *Bauhinia petersiana* subsp. *micrantha*, *Combretum collinum*, *Combretum engleri* and *Commiphora angolensis*, with a high density of *Dichrostachys cinerea* and *Acacia fleckii*, indicating an extreme state of encroachment. The grass cover is fairly sparse, on average only 18%. Some 52 species were found per 1000 m² (average) (Fig. 8).

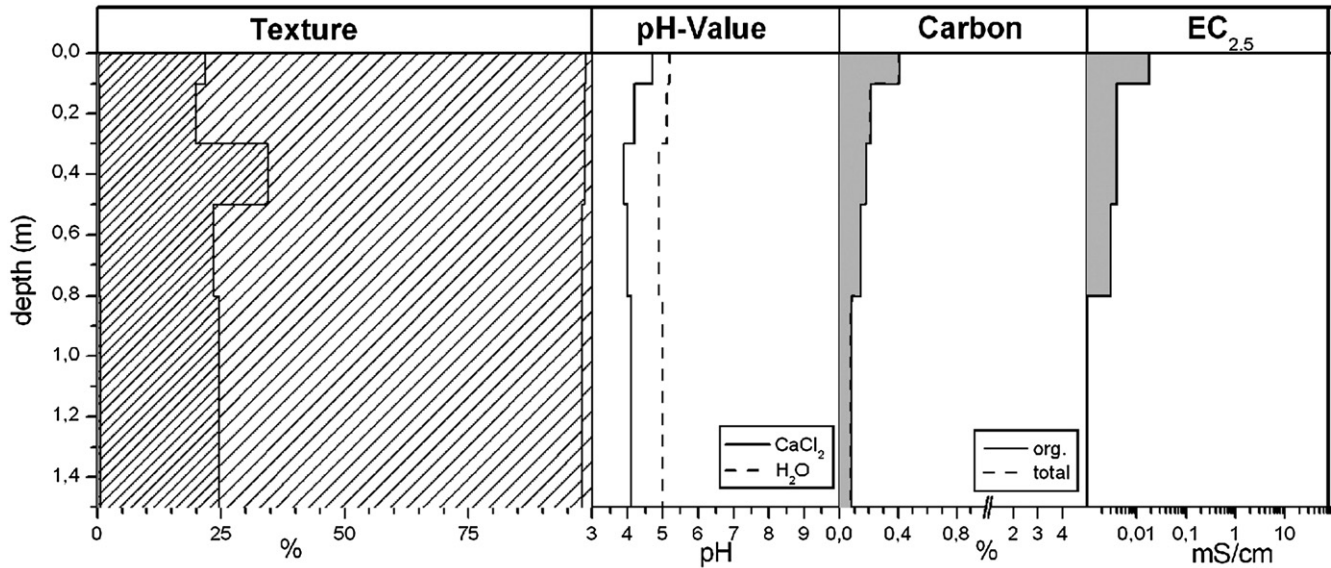


Fig. 7. Selected soil properties of a typical dystri-ferralic Arenosol.

Being so densely encroached, it is assumed that these shrublands and thickets are a result of severe degradation of the *Pterocarpus angolensis*–*Guibourtia coleosperma* woodlands, and/or the results of abandoned fields as part of a “slash-and-burn” cropping system. This is confirmed by the vegetation map: many *Acacia fleckii*–*Terminalia sericea* shrublands are found in the southern part of the Mile 46 LDC, where the cattle have been held over several years due to security risks, mainly predators and theft due to broken-down fencing as well as impassable paths in the northern parts of the station. Furthermore, these shrublands are often associated with present

settlements and fields, indicating them to be a result of slash and burn operations. This association covers 4272 ha (or 5.0%) of the study area.

3.7. The *Pterocarpus angolensis*–*Guibourtia coleosperma* moderately closed thicket association

Covering 63,342 ha (or 74.4%), this association is the most widespread within the study area and typical for the “Kavango woodlands”. The term “woodland” is a misconception: the structure is best described as a thicket due to a fairly well-developed shrub layer and high tree layer *sensu* Edwards (1983). The understory is, however, in most cases fairly open with an average of only 31% shrub cover, giving the impression of an open woodland (tree cover averaging 21%). The grass layer is fairly well developed, covering about 29%. Although palatable climax grasses like *Digitaria seriata*, *Schmidtia pappohoroides* and occasionally *Brachiaria nigropedata* are present, the sward is often dominated by annuals and/or sour grasses, e.g. *Urochloa brachyura*, *Perotis patens*, *Perotis leptopus*, *Melinis repens* subsp. *grandiflorum*, *Aristida stipitata* and *Aristida meridionalis*. Another souring factor is the very nutrient-poor deep sand. This nutrient deficiency is generally reflected in the nutritional value of the grazing for the animals.

The *Pterocarpus angolensis*–*Guibourtia coleosperma* bushland and thicket association is characterised by the presence of the phanerophyte species *Pterocarpus angolensis*, *Diplorhynchos condylocarpon*, *Guibourtia coleosperma*, *Ochna pulchra*, *Baikiaea plurijuga*, *Strychnos pungens* and *Strychnos cocculoides*. Geoxylic suffrutices (White, 1976) and chamaephytes like *Diospyros chamaethamnus*, *Fadogia* sp. cf. *thamnus*, *Lannea gossweileri* and *Gardenia brachythamnus* are also typical for this association. This association can be subdivided into four variants, which, due to their similarity in composition, are often difficult to distinguish. This is also very evident from the ordination diagram in Fig. 4.

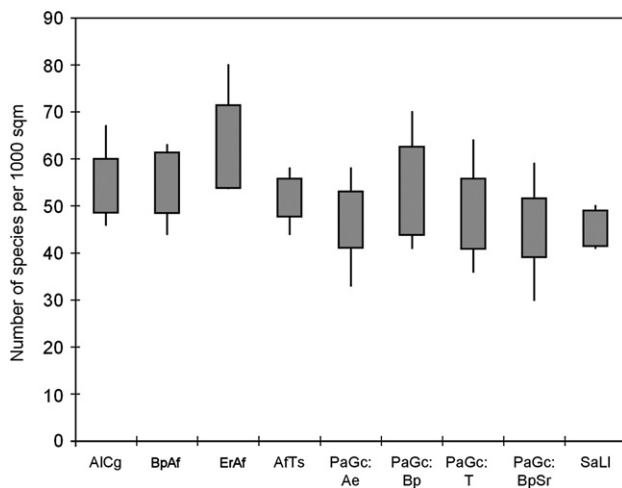


Fig. 8. Comparison of the species diversity of the different syntaxa described. The columns depict the standard deviation of species numbers, whilst the bars depict the range of species diversity (minimum and maximum number of species observed). Codes used: AICg: *Acacia luederitzii*–*Croton gratissimus* thickets, BpAf: *Bauhinia petersiana*–*Acacia fleckii* shrublands; ErAf: *Eragrostis rigidior*–*Acacia fleckii* bushlands; AfTs: *Acacia fleckii*–*Terminalia sericea* shrublands; PaGc: *Pterocarpus angolensis*–*Guibourtia coleosperma* thickets, with the variants: Ae: *Acacia erioloba* variant, Bp: *Bauhinia petersiana* variant; T: *Typicum* and BpSr: *Baikiaea plurijuga*–*Schinziophyton rautanenii* variant; SaLI: *Sartidia angolensis*–*Loudetia lanata* shrublands.

3.8. *The Acacia erioloba variant*

As the name indicates, this variant is characterised by the very prominent presence of *Acacia erioloba* trees or shrubs, whilst the absence of *Diospyros chamaethamnus*, *Ectadopsis oblongifolia*, *Tricholaena monachne*, *Schizachyrium jeffreysi*, *Securidaca longipendunculata* and *Strychnos pungens* trees (only low shrubs of this species occur here) is characteristic. The absence of these species, as well as the presence of *Acacia erioloba*, suggests a more loamy, shallower sand as substrate, compared to other woodland habitats. It is often associated with nearby *Eragrostis rigidior*–*Acacia fleckii* bushlands. The structure of this variant is typically a bushland, occasionally a thicket, with on average 9% tree cover, 49% shrub cover and 27% grass cover. On average 47 species were found per 1000 m² (Fig. 8).

3.9. *The Bauhinia petersiana variant*

This variant has an exceptionally high density of shrubs like *Bauhinia petersiana* subsp. *macrantha*, *Combretum collinum* and *Terminalia sericea*, indicating an encroached state of the woodlands, most likely through prolonged cattle grazing as well as protection from frequent fires by means of cutlines around the camps on the Mile 46 LDC. Being encroached, it harbours an average of 53 species per 1000 m² (Fig. 8), and displays a typically thicket-like structure with 18% tree cover, 33% shrub cover and 29% grass cover.

3.10. *The Typicum*

The typical *Pterocarpus angolensis*–*Guibourtia coleosperma* association displays a bushland to thicket-like structure, with averages of 21% tree cover, 32% shrub cover and 22% grass cover. Some 48 species were found on average per 1000 m² (Fig. 8).

3.11. *The Baikiaea plurijuga–Schinziohyton rautanenii variant*

This variant does not differ significantly from the *Typicum*, except for the fairly consistent presence of *Guibourtia coleosperma*, as well as the slightly more regular occurrence of *Baikiaea plurijuga* and the occasional occurrence of *Schinziohyton rautanenii*. Having less shrubs in the understory (averages of 21% shrub cover, 28% tree cover and 31% grass cover), the structure is more likely to be a woodland. Sites sampled varied between woodlands, bushlands and thickets. On average, 45 species were found per 1000 m² (Fig. 8).

3.12. *The Sartidia angolensis–Loudetia lanata open shrubland association*

This open shrubland association is closely associated with the *Pterocarpus angolensis*–*Guibourtia coleosperma* bushlands and thickets, but has, through the grasses *Sartidia angolensis*, *Loudetia lanata*, *Brachiaria serrata*, *Brachiaria dura*, *Andropogon schirensis*, *Schizachyrium sanguineum*, *Craspedorhachis rhodesiana*, *Monocymbium ceresiiforme* and *Elionurus muticus*, as well as the poisonous geoxylic suffrutex *Dichapetalum rhodesi-*

cum, a unique character. The presence of *Monocymbium ceresiiforme* and *Elionurus muticus* indicates leached soils with a low pH (Van Oudtshoorn, 1999; Gibbs Russell et al., 1990; Chippindall and Crook, 1976), whilst *Brachiaria dura* and *Craspedorachis rhodesiana* are often associated with moist to waterlogged soil conditions (own observations; Gibbs Russell et al., 1990). One exceptional relevé was sampled within a woodland in southern Mile 46 LDC, whilst all others were sampled in the headwater area of the Mpuku Omuramba along the eastern border of the LDC. Because of this habitat, as well as the composition, it has a high resemblance to the Western Zambesian grasslands (Vetter, 2001b), which also form the headwaters to the Zambesi river catchment along the border between Zambia and Angola.

Through water-logging of the soils, as well as frequent fires, the structure is typically a low, open shrubland with only few woody plant species (5 to 10% shrub cover). By fire protection inside Mile 46 LDC, however, the shrub component immediately increases to form moderately closed high shrublands to low bushlands (30 to 40% cover). The grass cover averages 45%, whilst the tree cover typically is only 1 to 2%. On average, 45 species have been found per 1000 m² (Fig. 8). This association is the most restricted, covering only 77.2 ha or 0.1% of the study area. Because of its limited distribution yet unique composition this association is fairly vulnerable.

4. Discussion

The above units form the basic units for land-use planning. In this area, two main land-uses are important; cropping and grazing. Wood harvesting for construction purposes and/or commercial/semi-commercial timber also poses a threat to the vegetation, particularly the large hardwood species, e.g. *Pterocarpus angolensis* and *Baikiaea plurijuga*. The former is presently being illegally harvested from the area (Strohbach and Strohbach, 2004), whilst *Baikiaea plurijuga* has been overexploited in the past for fencing material and timber (D. Amupolo, Station manager, pers. comm.). Numerous dead *Pterocarpus angolensis* trees in the area, without any apparent reason, are also of concern.

A more serious threat to biodiversity in the area, however, is the clearing for lands, as these inadvertently are made in the more nutrient-rich soils associated with the omiramba (eutric Arenosols). Exactly these vegetation types, the *Bauhinia petersiana*–*Acacia fleckii* shrublands and the *Eragrostis rigidior*–*Acacia fleckii* bushlands, are extremely limited in extent, covering together only 4.6% of the study area. Yet they harbour a fairly high diversity with 139 and 133 species each, or, compared to data from Strohbach and Strohbach (2004), about 40% of the total species richness of the study area. At the same time these two associations present the best grazing areas with a fairly palatable and nutritious grass sward. This in itself presents a conflict in land-uses, although may be not perceived as such by the local population. The LDC could play an important role in the long-term conservation of these vegetation types. In terms of land-use planning, further investigation into the grazing capacities and nutritive value of the grazing will be needed for the different units.

The effect of fire is debatable. Although Mendelsohn and el Obeid (2003) give evidence of the extent and severity of fire in

the Kavango, Geldenhuys (1977) argues also convincingly for the use of fires for maintaining the woodland ecosystem. Geldenhuys (1977) based his work on long-term observations in trial plots, whilst Mendelsohn and el Obeid (2003) base their conclusion on widespread observations whilst travelling through the region. At Mile 46 LDC the effect of fire prevention can be well illustrated: with prevailing easterly winds, fires are spreading westwards from the villages to the east of the LDC. They are partially stopped at either the cutline along the eastern border fence, or along the central passage running from south to north through the LDC. Shrub density in similar *Pterocarpus angolensis*–*Guibourtia coleosperma* bushland and thicket stands shows the least shrub cover outside (east of) the LDC, and the densest shrub cover within the western camps behind the central passage, where the fires are least likely to spread. Similar trends have been observed in various stands of the different associations within the Acacietea. Especially along the far north-eastern border of the LDC, the prevention of fires through the border cutline has led to the encroachment of *Bauhinia petersiana*–*Acacia fleckii* shrublands and *Eragrostis rigidior*–*Acacia fleckii* bushlands to form extensive *Acacia luederitzii*–*Croton gratissimus* thickets. This tendency to encroach due to lack of fires is detrimental to especially the grazing resource in the region.

The dense shrub cover within the woodlands can be seen as a regeneration process, however the dense understory can also mean a conflicting use of nutrient and water resources by the different strata. This could be a potential explanation for the death of large *Pterocarpus angolensis* trees mentioned earlier. Further investigations on the effect of fire, especially regarding the regeneration and production of hardwood species, are needed to clarify these questions.

Striking similarities are found in the pattern of soil distribution and broader vegetation units. Whereas the Burkeo–Pterocarpetea are restricted to the dystric Arenosols on deep, nutrient-poor sands with low pH values, the Acacietea are mainly found on the slightly finer textured and nutrient-richer eutric Arenosols of the omiramba and their surroundings. We assume that these differences are mainly driven by the water supply. The assumption is based on the theory that finer textured soils underlie a higher capillary rise and loss of the soil water from deeper horizons by evaporation. Therefore, the drying of a finer textured soil is often faster and reaches deeper than in a sandier texture. These aspects can be summarised in the “inverse texture hypothesis” which states that under arid or semi-arid climates with high potential evaporation rates the more sandy soils provide a better protection against evaporation. This theory was initially stated by Noy-Meir (1973) and strengthened by studies in different regions (e.g. Sala et al., 1988; Fernandez-Illescas et al., 2001; Laio et al., 2001; Rodriguez-Iturbe and Porporato, 2004).

Although both soil units of this study area consist mainly of sand, the small amount of clay and also the higher amount of fine sand in the eutric Arenosols results in a finer pore structure in the Acacietea which favour the faster evaporation. Moreover, the high intensities of rainfall events make run-off more likely than on the pure sands. The percolation and the water storage

reach deeper in the pure sands which also may affect the vegetation pattern by providing soil water in different depths.

The eutric Arenosols, although a nutrient poor soil, provide the better nutrient supply in comparison to the dystric Arenosols. This might be an additional factor for the differentiation of the vegetation structure, further investigations about the nutrient requirements of the different associations are necessary for the clarification of this hypothesis. Nevertheless, the similarities in the vegetation pattern and the soil distribution lay a useful basis for the regionalisation of soil units in this area by vegetation mapping with remote sensing techniques.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.sajb.2007.03.002](https://doi.org/10.1016/j.sajb.2007.03.002).

Note added in Proof

Nomenclature follows Arnold and de Wet (1993), as used in the TurboVeg database (updated 2000).

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