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Vegetation of the Thornbush Savanna of central Namibia: Baseline description of the present vegetation at Farm Erichsfelde, Otjozondjupa Region

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ABSTRACT

The Vegetation Survey of Namibia project has been initiated to provide baseline data in support of sustainable land-use planning. The finding of historical data from the Farm Erichsfelde initiated a long-term monitoring programme. This study serves as a baseline description of the vegetation associations. Regular Braun-Blanquet type sampling was done in April 1999, and additional relevés were obtained from the BIOTA project from 2002 and 2005. The entire data set comprised 232 relevés with 379 species. The data were classified using the modified TWINSPAN procedure. Eleven associations, grouped into five habitat types, were identified from the classification. These habitat types are linked to landscape facets, being wetlands, rocky habitats, plains, soils on calcretes as well as riverine and related habitats. The associations are described in terms of their composition, general position in the landscape and structure. The relevé data were subjected to an NMS ordination. The main environmental gradients identified were the topography, the soil pH and the slope of the landscape. It is, however, very clear from the ordination that the various associations identified are closely related, and in many respects ecotonal to each other. The vegetation associations were mapped using aerial images as well as the GPS position of the relevés as baseline. In addition, a Livestock Farming Suitability Index was calculated for each association, based on its habitat, composition and structure. Only the *Ziziphus mucronata–Dichanthium annulatum* association was rated highly suitable for livestock farming. The two plains associations, *Ondetia linearis–Acacia mellifera* and *Aristida congesta–Acacia mellifera* were rated moderately suitable, whilst all other associations were rated with a low suitability for livestock farming. The main reason for these fairly low ratings is a high degree of bush encroachment and low perennial grass cover.

Keywords: Acacietea; Livestock Farming Suitability Index; Modified TWINSPAN; Nonmetric Multidimensional Scaling; Phytosociology; Veld degradation

INTRODUCTION

Land use planning in Namibia, and specifically grazing planning, has for many years been based on a 'grazing capacity map' based on 'expert opinion' and dating from the 1970s (Departement Landbou Tegniese Dienste 1979). Changes in vegetation composition and structure, specifically through bush encroachment (Bester 1998, De Klerk 2004), have however also changed the productivity, specifically in terms of grazing capacity, of the semi-arid savannas of central Namibia. Although this has been realised as a problem for sustainable planning and management in the past (Lubbe 2005), few attempts have been undertaken to rectify this (Bester 1988, Espach 2006, Espach et al. 2009). One of the major drawbacks experienced is the lack of suitable baseline information. Presently available sources provide only broad overviews (cf. Giess 1998, Irish 1994, Mendelsohn et al. 2002), whilst more detailed descriptions are often limited to National Parks (Burke & Strohbach 2000).

The Vegetation Survey Project of Namibia has been initiated to provide some of the baseline information needed (in addition to soil and climatic descriptors) for land use planning (Strohbach 2001, 2014). Next to large-scale regional overview descriptions, an emphasis is placed on describing vegetation in greater detail in more localised, small-scale studies. This local detail serves also as seeding studies for the larger scale studies. The selection of Erichsfelde for such a localised, smaller-scale vegetation description came about with the availability of historic data collected in 1956 by Prof. H. Volk (Glen & Perold 2000) during a visit to the farm (Volk 1956). This study thus also serves as a baseline for a long-term monitoring programme to study vegetation changes.

METHODS

Study Area

The farm Erichsfelde is situated in the Okahandja District, Otjozondjupa Region in central Namibia, straddling the B6 trunk road between Okahandja and Otjiwarongo (Figure 1). The farm is 13,907.4 ha in size. The topography is an undulating plain as part of the agro-ecological zones CPL 2 (fringe plains) and CPL 3-4 (inselberg plains). The topography is generally flat, incised only by the major rivers (De Pauw et al. 1998, Petersen 2008). One dominating feature is the Ombotozo Mountain on the western border of the farm, which gives rise to several geological features on the western side of the farm. The mountain itself is based on mudstone of the Omingonde formation and topped by a gabbro sill, as part of the Karoo intrusive dolerite sills and dykes. The footslope of the Ombotozo, which reaches into Erichsfelde, consists of a talus slope of mixed weathered gabbro and weathered mudstones (Geological Survey 1980, South African Committee for Stratigraphy 1980, Schneider 2004). The plains to the east of this are formed by a sequence of syn- and post tectonic granites of the Salem Suite, undifferentiated schists and marbles of the Damara formation and undifferentiated granites of the Damara formation (Figure 1) (Geological Survey 1980). The Salem Suite granites are known to be alkaline (compared to the generally more acidic nature of granites) (Barnes & Sawyer 1980). This has important implications to soil characteristics in especially the western part of the farm.

The climate of Erichsfelde is a typical subtropical steppe climate following Köppen (1936). Rain occurs during the summer months between December and April (Figure 2) (Jürgens et al. 2010). Frost can occur during the winter months (June to August), but is generally restricted to between 5 and 10 days a year (Mendelsohn et al. 2002). The vegetation forms part of the Thornbush Savanna *sensu* Giess (1998).

Field surveys

Surveying followed the general method employed for the Vegetation Survey of Namibia project (Strohbach 2001, 2014). At each survey plot of 20 x 50 m, a Braun-Blanquet type relevé was compiled. All vascular plant species occurring were noted as well as their typical growth forms and estimated percentage crown cover. Habitat descriptors included the position using a GPS, the landscape, local topography, slope and aspect, lithology, degradation indicators, as well as a photograph. Unknown species and reference specimens were collected, identified and deposited at the National Herbarium of Namibia

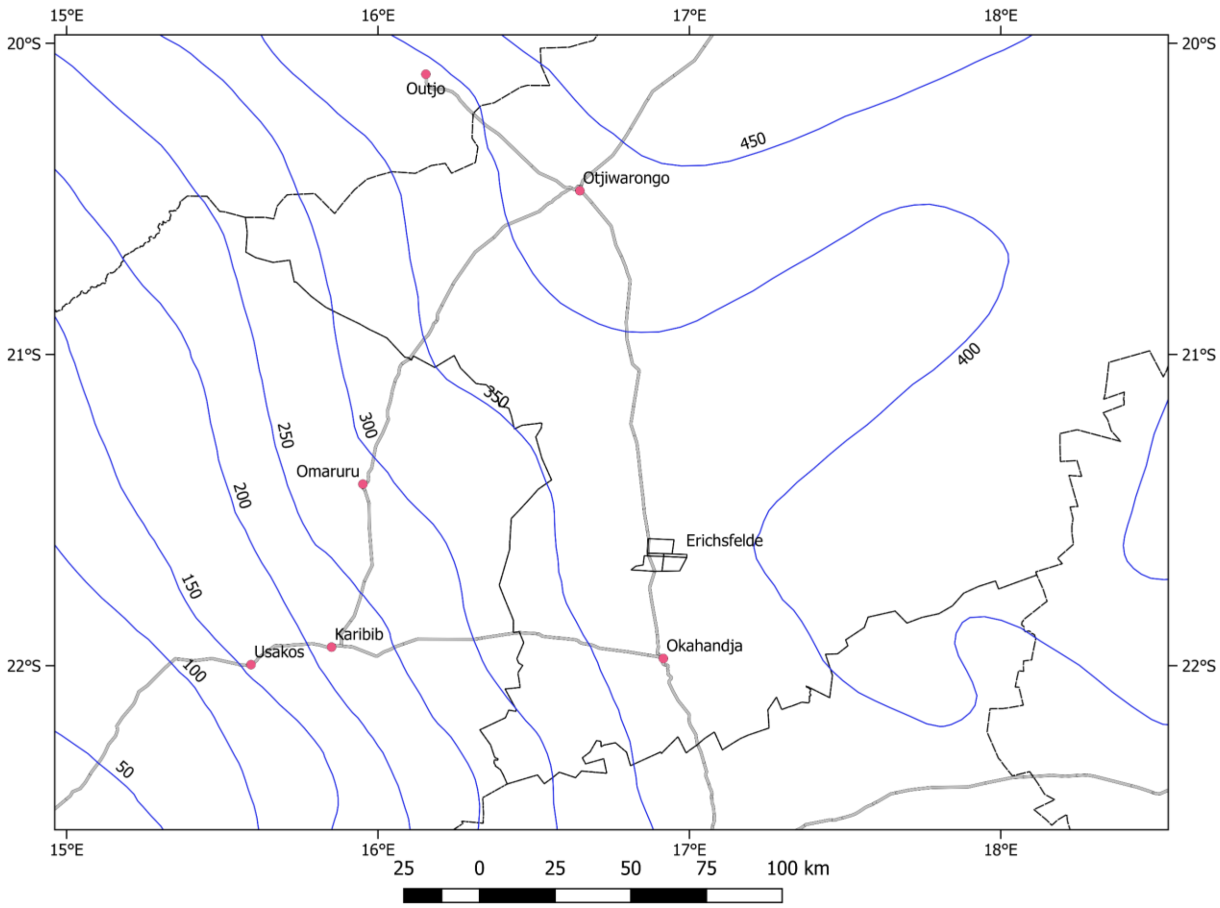

Figure 1*: (a) Overview map to show the position of Erichsfelde between Okahandja and Otjiwarongo in the Otjozondjupa Region. Long-term average annual rainfall isohyets are indicated in blue on the map.*

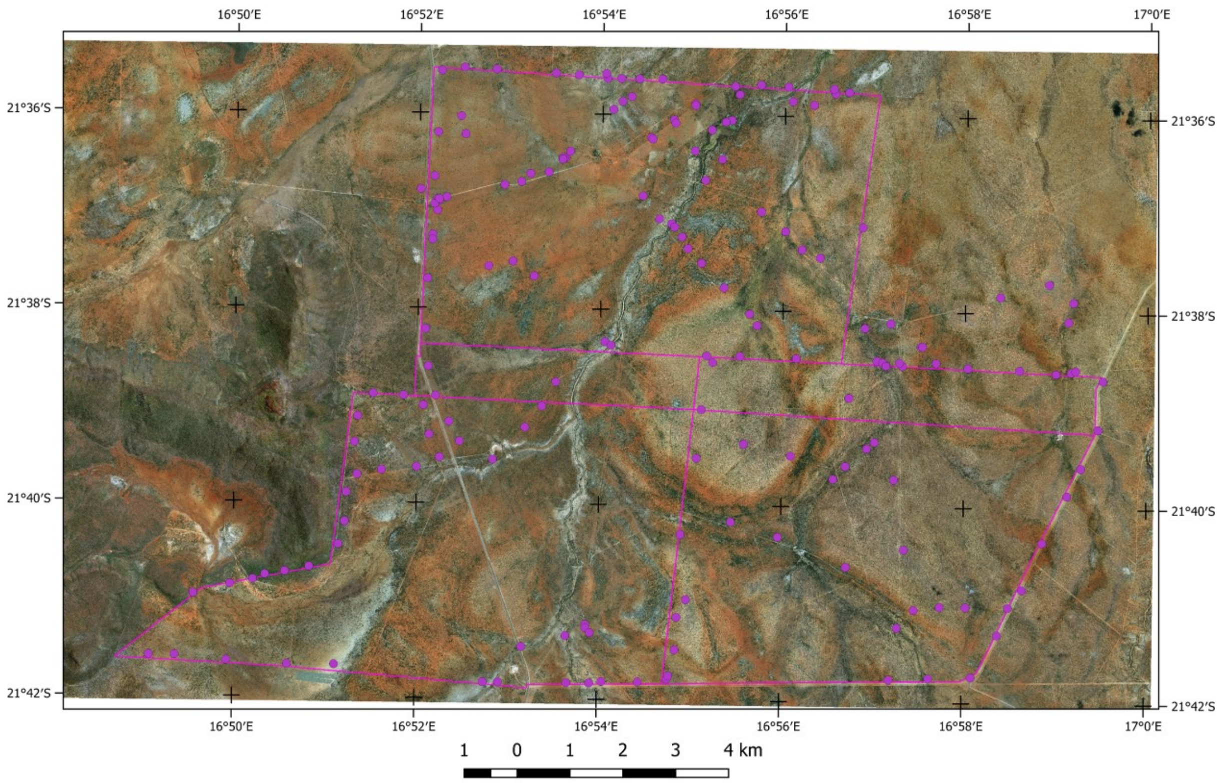

Figure 1: *(b) Aerial view of Erichsfelde, indicating the distribution of survey plots on the farm.*

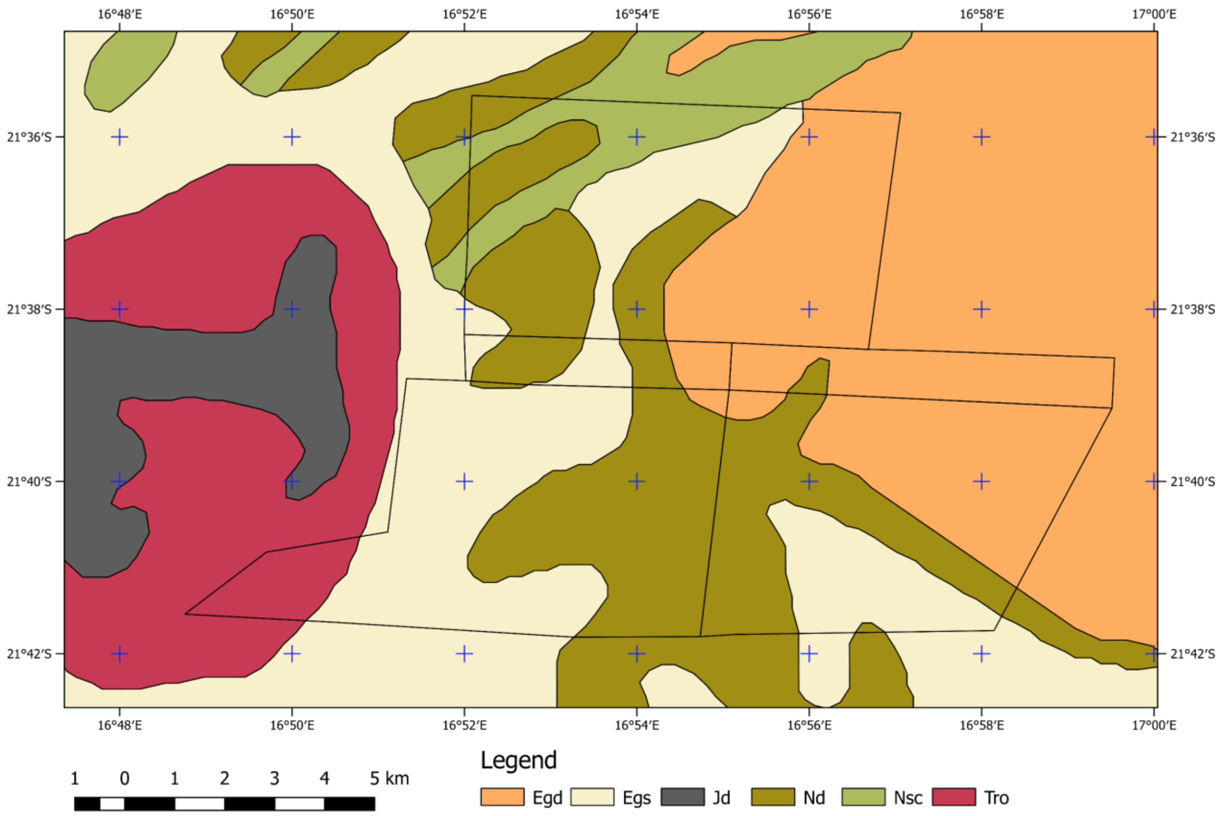

Figure 1: *(c) Geological map of Erichsfelde. Egd: Undifferentiated granites, Damara Sequence; Egs: Syn- and post tectonic granites of the Salem Suite; Jd: Intrusive dolerite sills and dykes; Nd: undifferentiated schists and marbles of the Nosib- and Swakop Groups, Damara Sequence; Nsc: marbles and schists of the Swakop Group, Damara Sequence; Tro: red mudstones and siltstones of the Omingonde Formation, Karoo Sequence. Data sources: Aerial images from Microsoft Bing Maps (undated), others: Geological Survey (1980) as well as NARIS (2001).*

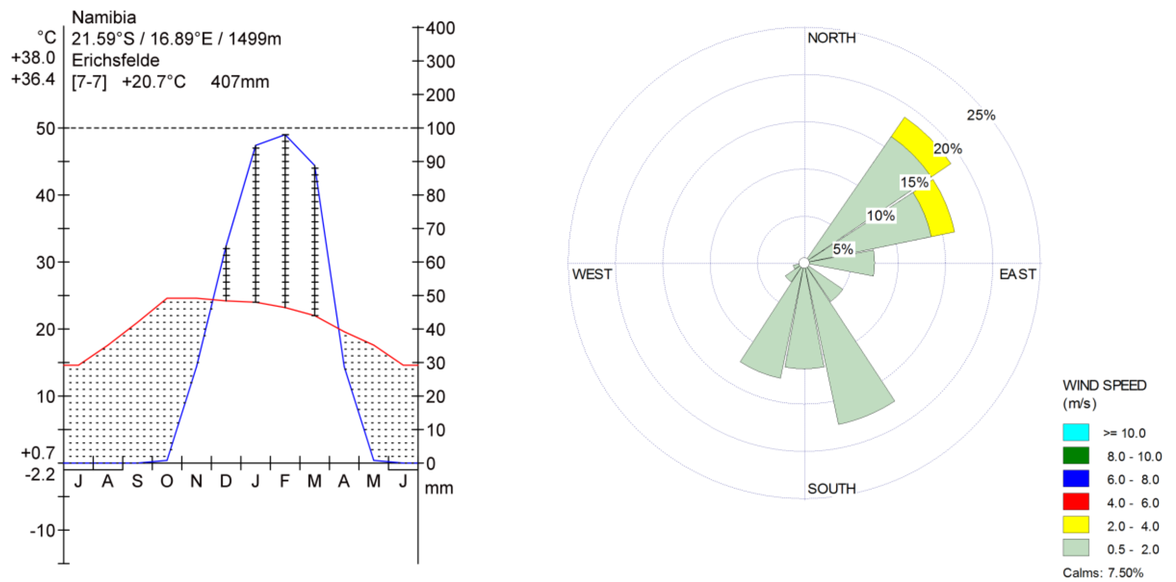

Figure 2: *(a) (left) Climate diagram for Erichsfelde. (b) (right) Wind rose of the prevailing wind directions and strengths at Erichsfelde. Source data: SASSCAL (2014).*

(WIND). The relevé data were captured on TurboVeg (Hennekens & Schaminée 2001). Nomenclature follows Klaassen & Kwembeya (2013).

The data were partially collected for the Vegetation Survey of Namibia Project, partially for the Biodiversity Transect Analysis in southern Africa (BIOTA) project (Jürgens et al. 2010, 2012). Specifically the relevés of Austermühle were collected at the Erichsfelde biodiversity observatory. The data collection follows the general survey scheme of the Vegetation Survey project, but due to the rigid layout of the biodiversity observatory, some of the relevés could span adjacent habitats. Austermühle also sampled several specific habitats outside the biodiversity observatory for general description purposes. A detailed overview of data sources and collectors is given in Table 1. All data form part of GIVD AF-NA-001 (Dengler et al. 2011, Strohbach & Kangombe 2012). The final, extended data set consisted of 232 relevés, with 379 species after cleanup procedures as described by Strohbach (2014).

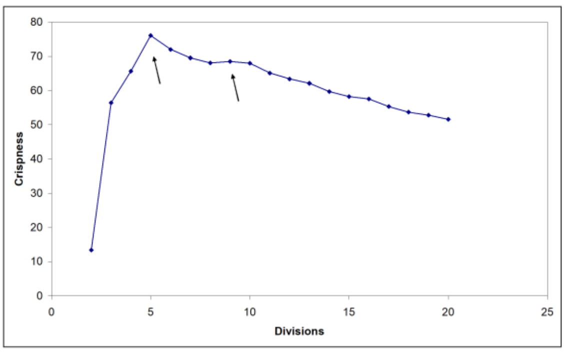

Figure 3: *Crispness values of the levels of subdivisions, indicating a clear peak at five subdivisions (at habitat level), and a lesser peak at nine subdivisions (vegetation association level). The peaks have been indicated by arrows.*

Data analysis

Data analysis followed methods commonly applied for the Vegetation Survey of Namibia project (Strohbach 2001, 2014, Strohbach & Jürgens 2010; see also Strohbach 2013a, b, 2017, Strohbach & Jankowitz 2012). As considerable observer bias, combined with seasonal bias (see seasonal rainfall figures in Table 1), was expected, it was decided to reduce the matrix for classification to phanerophytes, chamaephytes and graminoids only (i.e. the main components of a savanna ecosystem). Non-graminoid forbs, especially ephemeral forbs, were removed. The number of species was thus reduced to 132 species. This corresponds to the synusial approach of vegetation classification developed by Gillet & Julve (2018).

The classification was done with modified TWINSPAN (Roleček et al. 2009), using Total Inertia (Ter Braak 1986) as diversity measure. No pseudospecies were used for this classification. Crispness values (Botta-Dukát et al. 2005) for this classification indicated a highly reliable division into five clusters, and a less strong subdivision at nine clusters (Figure 3). The tenth subdivision (in crispness close to, but slightly lower than subdivision 9) would have resulted in splitting association 3.2 into two variants based on veld condition, and was thus ignored for this work.

Table 1: *Data sources used for this study. Rainfall data were made available by the farm manager of Erichsfelde. The quality of the season was determined according to criteria of Botha (1998) using long-term data from the farm.*

Surveyor	No of relevés (relevé sequence no)	Date of surveying	Rainfall for season (September to August)	Quality of rain season
B. Strohbach	145 (757 – 902)	April 1999	205 mm	Dry
T. Sheuyange	35 (903 – 938)	April 1999	205 mm	Dry
R. Austermühle	26 (50201 – 50226)	March to May 2002	233 mm	Dry
D. Wesuls	26 (10166 – 10191)	April 2005	357 mm	Normal

Upon inspection, it was found that Clusters 1 and 2 each represented two associations each, as observed during fieldwork. In the case of Cluster 2, it would have been split only with further divisions (16 divisions or more). This split was thus done manually. In the case of Cluster 1, a split was achieved using Cocktail (Bruelheide 2000), based on the presence/absence of *Dichanthium annulatum*, *Aerva leucura* and *Ziziphus mucronata* which were found to dominating an ephemeral riverine system. Once a stable classification was achieved, the previously removed forbs were again added to the data set for interpretation of the results and creation of the phytosociological and synoptic tables.

From the final classification, a synoptic table and a phytosociological table were created. Diagnostic species were determined using the phi co-efficient of association (Chytrý et al. 2002). For this calculation the numbers of relevés were standardised following Tichý & Chytrý (2006). Species with phi ≥40 were considered as diagnostic and with phi ≥60 as highly diagnostic; however, species with a non-significant fidelity at α=0.05 using Fisher's exact test were omitted. Species occurring with at least a 60% frequency were regarded as constant and with at least an 80% frequency as highly constant.

For each association an estimated number of species (as indicator of potential species richness) was calculated, using a first-order Jackknife procedure (Heltshe & Forrester 1983, Palmer 1990). This estimator is a function of the number of species occurring in only one relevé, and performed well in the estimation of species richness within forest environments in the USA (Palmer 1990).

Box-and-Whisker plots were constructed to illustrate the structure for each grouping (i.e. tree, shrub, dwarf shrub, perennial grass, annual grass and herb cover), using available growth form data (excluding the data from Wesuls, as these did not contain any growth form information). Description of the vegetation structure follows Edwards (1983). Two diversity indices, the Shannon Index (as an index of evenness) ($H' = -\Sigma\, p_i \ln p_i$) and Simpson's Index (as an index of dominance) ($D = \Sigma(n/N)^2$) (Peet 1974) were calculated for each relevé using Juice (Tichý et al. 2011).

Environmental gradients

A Nonmetric Multidimensional Scaling ordination (NMS) (Kruskal 1964) was calculated with PC-ORD version 7.02 (McCune & Mefford 2016). The data set was reduced by removing the relevé data from associations 1.1 and 1.2, as these would act as outliers due to their unique composition. For the species data, again only the reduced matrix with phanerophytes, chamaephytes and grasses was used in the NMS (as used during the initial classification).

Two secondary matrices were created: one for the physical environmental factors, the second for vegetation-related parameters. As categorical factors the association, the landscape type, and local topography, the lithology as well as the GIS-derived stratigraphy (based on Geological Survey 1980) were included. The available quantitative environmental factors were limited to the slope class. As no soil samples were taken during field work, no information on soil physical and chemical properties was available. However, with the presence of calcretes in several soils, and several wetland/riverine features, both the soil pH and the position in the landscape, relating to water flow patterns (cf. Pringle & Tinley 2003) were considered to be of importance in explaining the environmental gradients. Therefore, two proxy environmental factors were created as follows: Soils were classed as 'acidic' (6), 'neutral' (7) and 'basic' (8) based on the observed lithology, augmented by the stratigraphy. Granitic lithologies derived from the Damara formation were classed as 'acidic'; all schists, shales, mudstones as well as all fluvial system were classed as 'neutral', whilst all calcareous soils (including soils derived from the Salem Suite) were classed as 'basic'. This scheme broadly follows the lithological groupings of SOTER (FAO 1993). A second quantitative environmental factor was created from the landscape and local topography data associated with the relevé data. The observed local topography was sorted in a catena sequence (i.e. a reverse sequence of water flow/water accumulation in the landscape) and numbered, as listed in Table 2.

The second environmental matrix prepared contained structural data on the tree, tall shrub (>1 m), dwarf

Table 2: *Catena sequence used to convert categorical landscape and topographical data to numerical landscape data for use in NMS.*

Landscape	**Local topography**	**Catena sequence no**
Level land	Ephemeral river	1
	Ephemeral river embankment	2
	Floodplain	3
	Pan	4
	Wash	5
	Plain	6
Sloping land	Medium gradient footslope	7
	Rocky ridges	8
Steep land	Talus slope	9

shrub (<1 m), grass, herb and bare soil cover. These were additionally combined as a categorical structure parameter, i.e. woodlands, thickets, bushlands and shrublands, following Edwards (1983). Also included were the diversity indicators number of species per 1000 m^2, Shannon Index (H') and Simpson's Index (D).

The resulting data set had 226 relevés with 97 species, 13 environmental factors and 15 structural and biodiversity factors. Average Sørensen dissimilarity was used as distance measure, and the ordination was calculated in three dimensions (i.e. three resulting axes), based on an initial scree plot of stress versus dimensions (McCune et al. 2002, Peck 2010). The solutions were calculated with 200 iterations using real and 249 runs using randomised data for a Monte Carlo test. To aid the interpretation of the resulting scatter plots of the ordination results, the environmental, structural and biodiversity parameters were overlain as a joint plot onto a scatter diagram of the plots, with an r^2 cut-off level of 0.180.

Suitability for livestock farming

As the main aim of the Vegetation Survey Project is to support sustainable land use planning, a suitability rating for livestock farming was developed to help with the interpretation of vegetation classifications and descriptions as presented here (Strohbach 2018). This 'Livestock Suitability Index' is calculated based on the habitat, species composition and structure of the vegetation units. Habitat data were derived from the relevé data collected as well as GIS data sources, in particular the AEZ map (De Pauw et al. 1998) and the Namibian Soils Map (ICC et al. 2000). These spatial data however are at a rather course scale (1:1,000,000), but represent the best available habitat data for Namibia at present. For the factor 'Water Holding Capacity' within the Habitat Subindex, data from ICC et al. (2000) were adapted in the sense that only the rocky habitats (habitat cluster 2) was regarded as having extremely low water holding capacity (factor 20), whilst all calcrete habitats (habitat cluster 4) were regarded as having low water holding capacity (factor 40). All other habitats were classed, as per ICC et al. (2000) data, as 'moderate to high' with a factor of 120.

For the compositional data, species attributes were obtained from the following sources: species toxicity data were derived from Mannheimer et al. (2012), whilst grass palpability and ecological status was derived from Müller (2007) and Gibbs Russell et al. (1990). All other required data were derived from the relevé data.

Mapping

A vegetation map was created using Google Earth and Microsoft Satellite (Bing) imagery as baseline. The Google Earth and Microsoft Satellite maps were used complementary to each other, as the Google Earth Map was a wet-season image (2/1/2010) showing vegetation features well, whilst the Microsoft Satellite map was an apparent dry season map (undated), showing soil features well. Using the position of the classified relevés as ground truth points, a map was manually digitized by visual interpretation in QGIS software package (QGIS 2.14.5-Essen 2016).

RESULTS

Classification results

The classification resulted in five higher syntaxonomic groups, and eleven associations. These classification results are depicted in Figure 4 as a dendrogram. The full phytosociological table is presented as downloadable online Appendix 1, the synoptic table as online Appendix 2. As this study covers only a fairly small part of the Thornbush Savanna *sensu* Giess (1998), or the Acacietea *sensu* Volk & Leippert (1971), no attempt has been made to describe the higher syntaxonomic groupings apart from associating them with a particular landscape facet or broad habitat type on the farm.

The associations are not described formally according to the International Code for Phytosociological Nomenclature (ICPN) (Weber et al. 2000), pending further descriptions of the vegetation of the greater Thornbush Savanna *sensu* Giess (1998). Within the synopsis, highly diagnostic species (with phi coefficient >60), highly constant species (occurring in more than 80% of relevés) and dominant species (with on average more than 30% crown cover) are indicated in **bold**. All structural descriptions follow Edwards (1983).

1. Wetlands

1.1. *Ziziphus mucronata–Dichanthium annulatum* association on ephemeral river beds with heavy soils
Synopsis:
Number of relevés: 2
Number of species observed: 44
Estimated number of species: 60
Average species density per 1000 m^2: 32

Diagnostic species: ***Tagetes minuta***, ***Gomphrena celosioides***, ***Aerva leucura***, ***Solanum lichtensteinii***, ***Dichanthium annulatum* var. *papillosum***, ***Eragrostis lehmanniana***, ***Trichodesma angustifolium***, ***Osteospermum muricatum* subsp. *muricatum***, ***Ruelliopsis damarensis***, ***Nicolasia stenoptera* subsp. *stenoptera***, *Xanthium spinosum*, *Tribulus terrestris*, *Hibiscus trionum*, *Platycarphella carlinoides*, *Alternanthera pungens*, *Solanum delagoense*, *Sesbania macowaniana*, *Ziziphus mucronata*, *Setaria verticillata*, *Eragrostis rotifer*, *Oxygonum alatum*, *Panicum coloratum*, *Chloris virgata*, *Schkuhria pinnata*, *Indigofera holubii*
Constant species: ***Urochloa brachyura***, ***Kyphocarpa angustifolia***, ***Cenchrus ciliaris***, ***Acacia tortilis* subsp. *heteracantha Acacia mellifera,* subsp. *detinens***
Dominant species: ***Dichanthium annulatum* var. *papillosum***

This association occurs in a small tributary on the south-western part of the farm draining the mud plains of the *Anthephora schinzii–Leucosphaera bainesii* association (number 5.2 below). The topography is a fairly deeply incised water channel with heavy clay soils as river bed. With *Acacia tortilis*, *Aerva leucura* and *Ziziphus mucronata*, prominent elements of the regular riverine thickets (see 5.3 below) are present, indicating a close relationship to these. The striking feature though is a dense grass sward of *Dichanthium annulatum* and other perennial grass species. The typical structure is thus a tall, closed grassland (Figures 5a and 6a).

1.2. *Marsilea–Leptochloa fusca* association of the vlei areas

Synopsis:
Number of relevés: 4
Number of species observed: 38
Estimated number of species: 55
Average species density per 1000 m^2: 19

Diagnostic species: ***Eragrostis leersiiformis***, ***Marsilea ephippiocarpa***, ***Schoenoplectus muricinux***, ***Sporobolus nebulosus***, ***Leptochloa fusca***, ***Cyperus difformis***, ***Vahlia capensis***, ***Nesaea drummondii***, ***Mollugo nudicaulis***, ***Artemisiopsis villosa***, ***Courtoisina assimilis***, ***Cotula anthemoides***, *Portulaca oleracea*, *Panicum pilgerianum*, *Heliotropium baclei* var. *rostratum*, *Amaranthus thunbergii*, *Listia marlothii*, *Cucumis sagittatus*, *Phyllanthus fraternus*
Constant species: *Eragrostis rotifer*, *Aristida adscensionis*
Dominant species: ***Marsilea ephippiocarpa***, ***Eragrostis leersiiformis***

This association is typical for the vlei areas (shallow depressions with temporary, seasonal standing water). These occur occasionally in the shallow *omiramba* (King 1963) as part of the drainage system crossing the farm. The structure is a short, closed grassland (Figures 5b and 6b), surrounded by a fringe of dense, thicket-like vegetation.

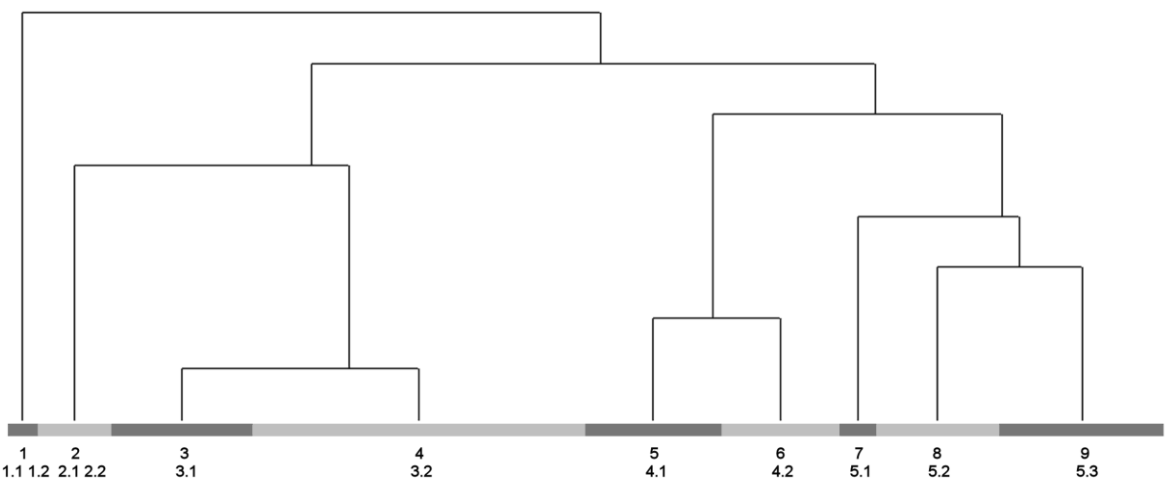

Figure 4: *Dendrograms depicting the classification results. The upper row numbers represent the cluster numbers, the lower row numbers correspond to the numbering of the association descriptions.*

2. Rocky habitats

2.1. *Andropogon gayanus–Combretum apiculatum* association on granitic outcrops

Synopsis:
Number of relevés: 4
Number of species observed: 31
Estimated number of species: 52
Average species density per 1000 m^2: 23

Diagnostic species: ***Triraphis ramosissima***, ***Helichrysum tomentosulum* subsp. *tomentosulum***, ***Combretum apiculatum* subsp. *apiculatum***, ***Tephrosia dregeana* var. *dregeana***, ***Barleria lancifolia***, ***Acacia erubescens***, ***Tephrosia villosa* subsp. *ehrenbergiana* var. *ehrenbergiana***, ***Melinis repens* subsp. *repens***, ***Andropogon gayanus* var. *polycladus***, ***Heteropogon contortus***, *Waltheria indica*, *Searsia marlothii*, *Cleome rubella*, *Grewia bicolor*, *Grewia flavescens*, *Ximenia americana*, *Tavaresia barklyi*, *Maerua parvifolia*, *Hibiscus micranthus*
Constant species: Dichrostachys ***cinerea***, ***Boscia albitrunca***, *Pogonarthria fleckii*
Dominant species: ***Dichrostachys cinerea***

This association is limited to a small granitic outcrop near the entrance gate of Erichsfelde. A similar outcrop was observed ca 250 m west of this on the neighbouring farm Matador. This outcrop is associated with the syn- to post tectonic granites of the Salem suite occurring to the west of the study area (Geological Survey 1980). The slope's steepness is between 10 and 15%, with a high rock cover of over 80%. The outcrop rises barely 3 to 5 m above the surrounding plain. The vegetation structure is a high, semi-open shrubland (Figures 5c and 6c).

2.2. *Maerua parvifolia–Acacia erubescens* association of the mountain slopes

Synopsis:
Number of relevés: 11
Number of species observed: 42
Estimated number of species: 81
Average species density per 1000 m^2: 34

Diagnostic species: ***Acacia senegal***, ***Grewia bicolor***, ***Megalochlamys marlothii***, ***Grewia retinervis***, *Maerua parvifolia*, *Grewia villosa*, *Montinia caryophyllacea*, *Helinus integrifolius*, *Cordia sinensis*, *Acacia erubescens*, *Boscia foetida*, *Albizia anthelmintica*, *Commiphora tenuipetiolata*
Constant species: ***Dichrostachys cinerea***, ***Leucosphaera bainesii***, ***Aristida adscensionis***, ***Enneapogon cenchroides***, ***Boscia albitrunca***, *Monechma genistifolium* subsp. *genistifolium*, *Hibiscus micranthus*, *Lycium eenii*, *Acacia mellifera* subsp. *detinens*
Dominant species: ***Dichrostachys cinerea***, ***Acacia erubescens***, *Leucosphaera bainesii*, *Acacia senegal*, *Acacia mellifera* subsp. *detinens*

This association represents the vegetation of the southern and eastern footslopes of the Ombotozo Mountain. The slopes are moderately steep to steep (15-60%), and consist of a talus with a high stone and rock cover. The main lithology of the bottom slope is mudstones of the Omingonde formation (Ecca Group, Karoo Sequence) (Geological Survey 1980, South African Committee for Stratigraphy 1980) as well as decomposed gabbro (Schneider 2004). The upper slopes of the mountain consist of olivine gabbro as part of wide-spread intrusive sills and dykes of the Karoo Sequence (Geological Survey 1980, South African Committee for Stratigraphy 1980, Schneider 2004). The vegetation structure is a high, closed shrubland (Figures 5d and 6d), not reaching more than 5 to 6 m.

3. Plains habitat

3.1. *Ondetia linearis–Acacia mellifera* association of the omiramba

Synopsis:
Number of relevés: 28
Number of species observed: 130
Estimated number of species: 189
Average species density per 1000 m^2: 45

Diagnostic species: ***Tetragonia calycina***, ***Ondetia linearis***, *Raphionacme lanceolata*, *Aristida congesta* subsp. *congesta*, *Indigofera rautanenii*, *Cucumis anguria*, *Phyllanthus pentandrus*, *Vigna oblongifolia* var. *parviflora*, *Hermannia modesta*, *Persicaria hystricula*, *Commelina livingstonii*, *Helinus spartioides*, *Cyphostemma cirrhosum*, *Ocimum filamentosum*, *Xerophyta humilis*, *Phaeoptilum spinosum*, *Tephrosia burchellii*, *Euphorbia prostrata*, *Coccinia rehmannii*
Constant species: ***Kyphocarpa angustifolia***, ***Geigeria acaulis***, ***Boscia albitrunca***, ***Grewia flava***, ***Urochloa brachyura***, ***Aristida adscensionis***, ***Acacia mellifera* subsp. *detinens***, ***Ptycholobium biflorum* subsp. *angolensis***, ***Lycium eenii***, ***Eragrostis porosa***, ***Dichrostachys cinerea***, ***Barleria lanceolata***, *Pogonarthria fleckii*, *Leucosphaera bainesii*, *Tragus berteronianus*, *Ehretia rigida*, *Pupalia lappacea*, *Melinis repens* subsp. *grandiflora*, *Cleome rubella*, *Aristida rhiniochloa*, *Stipagrostis uniplumis* var. *uniplumis*, *Dicoma tomentosa*, *Catophractes alexandri*, *Albizia anthelmintica*
Dominant species: ***Eragrostis porosa***, ***Acacia mellifera* subsp. *detinens***, ***Dichrostachys cinerea***, *Albizia anthelmintica*, *Stipagrostis uniplumis* var. *uniplumis*, *Ondetia linearis*, *Gisekia africana*, *Catophractes alexandri*, *Boscia albitrunca*, *Aristida*

adscensionis, *Acacia reficiens*, *Acacia hebeclada* subsp. *hebeclada*

This association is typical of the shallow watercourses that form the headwaters of the bigger ephemeral rivers. Typical for *omiramba*, no clear gradient is visible in the landscape (King 1963). These *omiramba* are often only recognisable by a lusher vegetation, generally dominated by *Ondetia linearis*. The vegetation is densely encroached by *Acacia mellifera* subsp. *detinens*, forming a tall, closed shrubland (Figures 5e and 6e).

3.2. *Aristida congesta–Acacia mellifera* association of the sandy plains (Strohbach 2002)

Synopsis:
Number of relevés: 67
Number of species observed: 148
Estimated number of species: 258
Average species density per 1000 m^2: 40

Diagnostic species: *Evolvulus alsinoides*, *Aristida congesta* subsp. *congesta*, *Ipomoea sinensis*, *Felicia smaragdina*, *Gisekia africana*
Constant species: ***Stipagrostis uniplumis* var. *uniplumis***, ***Acacia mellifera* subsp. *detinens***, ***Boscia albitrunca***, ***Pogonarthria fleckii***, ***Eragrostis porosa***, ***Kyphocarpa angustifolia***, ***Urochloa brachyura***, *Aristida adscensionis*, *Tragus berteronianus*, *Talinum arnotii*, *Ptycholobium biflorum* subsp. *angolensis*, *Enneapogon cenchroides*, *Lycium eenii*, *Pupalia lappacea*, *Lycium bosciifolium*, *Dicoma tomentosa*, *Melinis repens* subsp. *grandiflora*, *Geigeria acaulis*
Dominant species: ***Stipagrostis uniplumis* var. *uniplumis***, ***Acacia mellifera* subsp. *detinens***, *Eragrostis porosa*, *Monechma genistifolium* subsp. *genistifolium*, *Dichrostachys cinerea*, *Aristida congesta* subsp. *congesta*, *Aristida adscensionis*, *Lycium eenii*, *Grewia flava*, *Eragrostis lehmanniana*, *Acacia reficiens*

Strohbach (2002) described this association previously (her association 7 - *Acacia mellifera–Aristida congesta* association[1]) as occurring on chromic Cambisols with sandy loam texture in the topsoil. For the Otjiamongombe Observatory (situated near the north-eastern corner of Erichsfelde), haplic Luvisols, with reddish clayey, slightly acidic soils have been described (Jürgens et al. 2010 pp. 195–221). The association occurs on nearly flat to slightly undulating plains (0-5% slope). The structure of the vegetation is a short moderately closed bushland (Figures 5f and 6f). However, it is prone to encroachment, especially by *Acacia mellifera* subsp. *detinens*, turning it into a high, closed shrubland.

4. Shallow soils on calcretes

Especially in the western parts of the farm the subsurface Salem Suite granites form undulating plains with shallow soils on extensive calcrete deposits. The larger ephemeral rivers also eroded into the pediplane, exposing the subsurface calcretes in their floodplains. Depending on the depth of the soil profile, two different associations occur:

4.1. *Acacia mellifera—Monechma genistifolium* association (Strohbach 2002)

Synopsis:
Number of relevés: 27
Number of species observed: 80
Estimated number of species: 204
Average species density per 1000 m^2: 32

Diagnostic species: Enneapogon *desvauxii*
Constant species: ***Acacia mellifera* subsp. *detinens***, ***Enneapogon cenchroides***, ***Leucosphaera bainesii***, ***Acacia tortilis* subsp. *heteracantha***, *Monechma genistifolium* subsp. *genistifolium*, *Cenchrus ciliaris*, *Eragrostis porosa*, *Aristida adscensionis*, *Boscia albitrunca*, *Stipagrostis uniplumis* var. *uniplumis*, *Eragrostis annulata*
Dominant species: ***Monechma genistifolium* subsp. *genistifolium***, ***Leucosphaera bainesii***, ***Acacia mellifera* subsp. *detinens***, ***Acacia reficiens***, ***Stipagrostis uniplumis* var. *uniplumis***, *Cenchrus ciliaris*, *Catophractes alexandri*, *Aristida effusa*, *Anthephora schinzii*, *Acacia tortilis* subsp. *heteracantha*

Within the study area, these bushlands are generally found adjacent to riverine thickets (association 5.1 below) on loamy floodplain deposits, as well as on suboutcropping calcrete banks. Strohbach (2002) describes this association as a transitional association between the *Boscia foetida–Leucosphaera bainesii* association on shallow calcretes, and the deep, sandy-soiled *Aristida congesta–Acacia mellifera* association. The soils are described as chromic Cambisols or leptic-chromic Cambisols by Strohbach (2002), as well as calcic Cambisols and petric Calcisols by Jürgens et al. (2010). Often the underlying calcrete gravels become visible, contributing to the xeric nature of these soils (Figure 6g). The structure is typically a short, semi-open bushland (Figure 5g). There is a distinct resemblance to the *Monechma genistifolium–Acacia tortilis* association (5.3.), which however occurs as an

[1] The association name has been changed by reversing the two name-giving species, in order to conform to naming concepts of the ICPN (the landscape-dominating species is mentioned last) (Weber et al. 2000).

ecotone (transistion) to the sandy plains of the *Aristida congesta–Acacia mellifera* association.

4.2. *Boscia foetida–Leucosphaera bainesii* association on shallow calcareous soils (Strohbach 2002)

Synopsis:
Number of relevés: 24
Number of species observed: 69
Estimated number of species: 180
Average species density per 1000 m^2: 34

Diagnostic species: ***Eriocephalus luederitzianus***, ***Sericorema sericea***, *Hermannia damarana*, *Enneapogon desvauxii*, *Sida ovata*, *Tragus racemosus*, *Oropetium capense*

Constant species: ***Monechma genistifolium* subsp. *genistifolium***, ***Leucosphaera bainesii***, ***Grewia flava***, ***Acacia mellifera* subsp. *detinens***, ***Cenchrus ciliaris***, ***Stipagrostis uniplumis* var. *uniplumis***, *Eragrostis porosa*, *Enneapogon cenchroides*, *Catophractes alexandri*, *Acacia reficiens*
Dominant species: ***Monechma genistifolium* subsp. *genistifolium***, ***Acacia mellifera* subsp. *detinens***, ***Stipagrostis uniplumis* var. *uniplumis***, ***Enneapogon desvauxii***, ***Acacia reficiens***, *Acacia tortilis* subsp. *heteracantha*, *Leucosphaera bainesii*, *Enneapogon cenchroides*, *Catophractes alexandri*

This association has been previously described by Strohbach (2002) as her association 10. One conspicuous difference is that the name-giving species, *Boscia foetida*, occurs here on only nine of the relevés, on i.e. less than 50%, compared to the

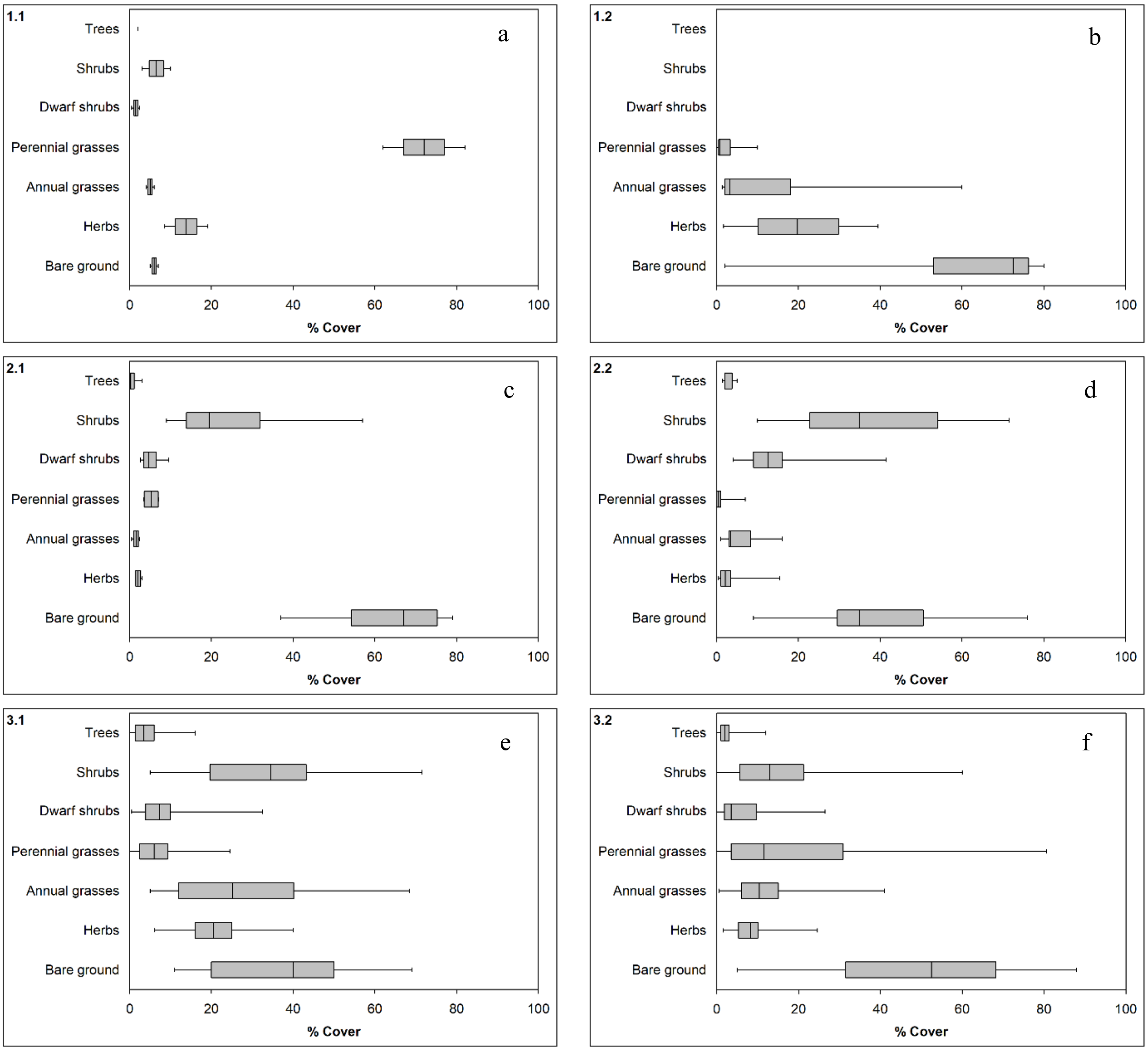

Figure 5: *Box-and-Whisker plots of the average structure of the various associations. (a)* Ziziphus mucronata–Dichanthium annulatum *association; (b)* Marsilea–Leptochloa fusca *association; (c)* Andropogon gayanus–Combretum apiculatum *association; (d)* Maerua parvifolia–Acacia erubescens *association; (e)* Ondetia linearis–Acacia mellifera *association; (f)* Aristida congesta–Acacia mellifera *association.*

70% frequency described by Strohbach (2002). The *Boscia foetida–Leucosphaera bainesii* association occurs on shallow leptic Calcisols (shallow stony soils on calcrete), often associated with suboutcropping rocks of the Damara Sequence (Strohbach 2002, Petersen 2008). Although the dominant structure of the vegetation is a low, semi-open bushland (Figure 5h), it has a dense dwarf-shrub layer associated with the calcretes (Figure 6h).

5. Riverine habitats

5.1. *Ziziphus mucronata–Acacia tortilis* association of the riparian thickets

Synopsis:
Number of relevés: 7
Number of species observed: 95
Estimated number of species: 158
Average species density per 1000 m^2: 31

Diagnostic species: ***Asparagus cooperi***, ***Cymbopogon caesius***, ***Achyranthes aspera* var. *aspera***, *Vernonia fastigiata*, *Searsia ciliata*, *Ziziphus mucronata*, *Eragrostis trichophora*, *Pentarrhinum insipidum*, *Leucas glabrata*, *Tarchonanthus camphoratus*, *Chenopodium murale*, *Eragrostis echinochloidea*, *Brachiaria malacodes*, *Lantana angolensis*
Constant species: ***Pupalia lappacea***, ***Cenchrus ciliaris***, ***Acacia mellifera* subsp. *detinens***, ***Grewia flava***, ***Acacia tortilis* subsp. *heteracantha***, *Setaria verticillata*, *Monechma genistifolium* subsp. *genistifolium*, *Lycium eenii*, *Lycium bosciifolium*, *Eragrostis rotifer*, *Barleria lanceolata*

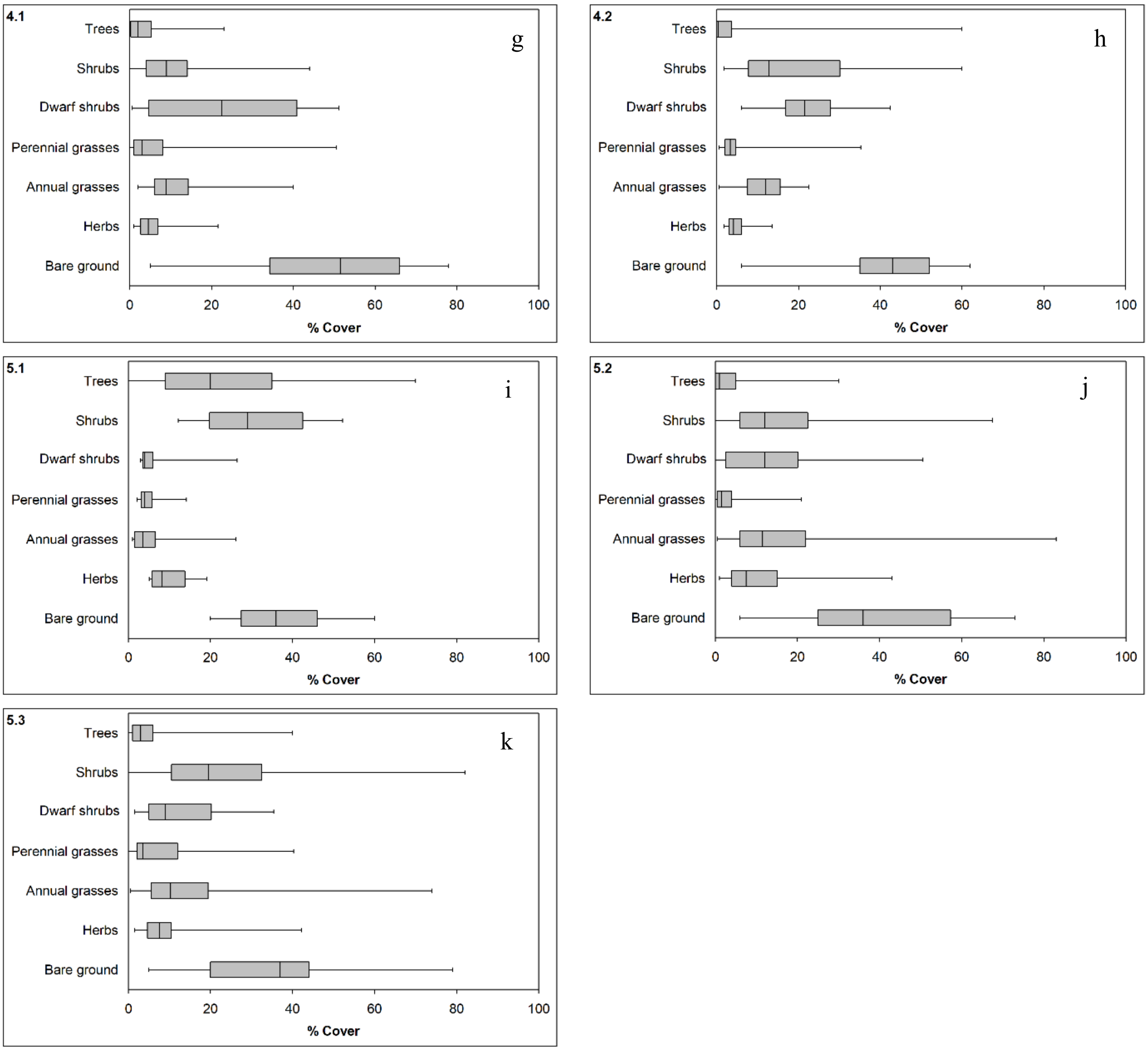

Figure 5 continued: *Box-and-Whisker plots of the average structure of the various associations. (g)* Acacia mellifera–Monechma genistifolium *association; (h)* Boscia foetida–Leucosphaera bainesii *association; (i)* Ziziphus mucronata–Acacia tortilis *association; (j)* Anthephora schinzii–Leucosphaera bainesii *association; (k)* Monechma genistifolium–Acacia tortilis *association.*

Dominant species: ***Acacia mellifera* subsp. *detinens***, ***Acacia tortilis* subsp. *heteracantha***, ***Ziziphus mucronata***, ***Achyranthes aspera* var. *aspera***

A large ephemeral river, with two smaller, but equally incised tributaries, forms the main drainage from south to north through the centre of Erichsfelde. The *Ziziphus mucronata–Acacia tortilis* association forms the ca 5 to 10 m wide embankment to these well-developed, deeply incised rivers. The riparian vegetation forms a short, sub-continous thicket, which is gradually replaced by the bushlands of the *Acacia mellifera—Monechma genistifolium* association (Figures 5i and 6i).

5.2. *Anthephora schinzii–Leucosphaera bainesii* clay soils association

Synopsis:
Number of relevés: 25
Number of species observed: 91
Estimated number of species: 190
Average species density per 1000 m^2: 31

Diagnostic species: *Aristida hordeacea*
Constant species: ***Acacia mellifera* subsp. *detinens***, ***Aristida adscensionis***, *Urochloa brachyura*, *Acacia tortilis* subsp. *heteracantha*, *Lycium eenii*, *Leucosphaera bainesii*, *Setaria verticillata*, *Chloris virgata*, *Cenchrus ciliaris*
Dominant species: ***Acacia mellifera* subsp. *detinens***, ***Leucosphaera bainesii***, ***Aristida adscensionis***, *Eragrostis porosa*, *Acacia tortilis* subsp. *heteracantha*, *Setaria verticillata*, *Enneapogon cenchroides*, *Dichrostachys cinerea*, *Chloris virgata*,

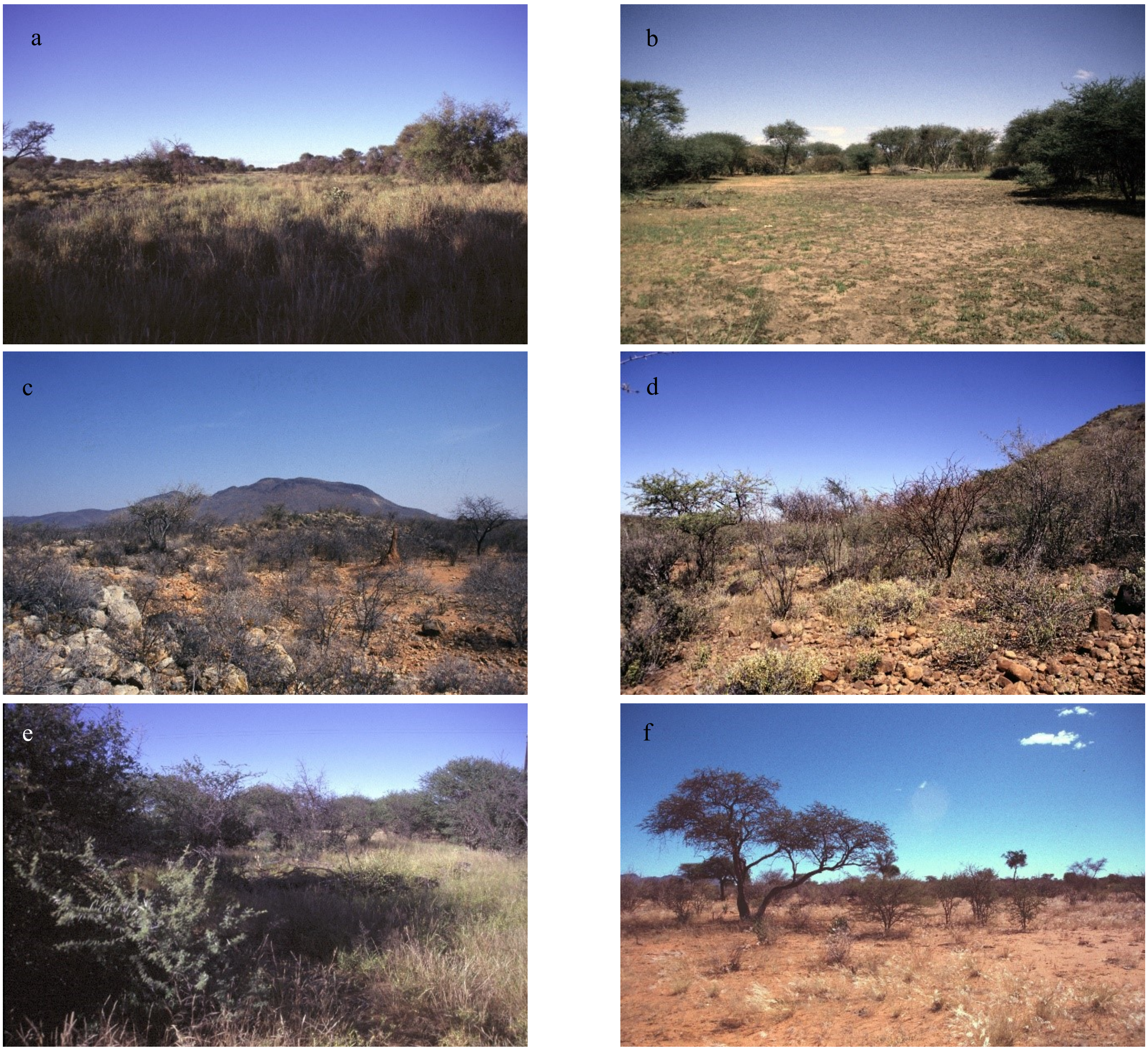

Figure 6: *Typical views of the various associations. (a)* Ziziphus mucronata–Dichanthium annulatum *association (relevé 901); (b)* Marsilea–Leptochloa fusca *association (relevé 770); (c)* Andropogon gayanus–Combretum apiculatum *association (relevé 789); (d)* Maerua parvifolia–Acacia erubescens *association (relevé 887); (e)* Ondetia linearis–Acacia mellifera *association (relevé 909); (f)* Aristida congesta–Acacia mellifera association *(relevé 829)*

Cenchrus ciliaris, *Bidens biternata*, *Anthephora schinzii*

At the base of the Ombotozo Mountain, a series of washes have developed with heavy clay soils as a product of weathering of the mudstones of the Omingonde formation. On these heavy soils the *Anthephora schinzii–Leucosphaera bainesii* association occurs. A few relevés of this association occur also on loamy floodplains in a mosaic with the *Monechma genistifolium–Acacia tortilis* association. Although the structure is a high, open shrubland dominated by *Acacia mellifera*, the actual diagnostic feature of this association is the dwarf shrub understorey dominated by *Leucosphaera bainesii* in association with the annual grass *Anthephora schinzii* (Figures 5j and 6j).

5.3. *Monechma genistifolium–Acacia tortilis* association

Synopsis:
Number of relevés: 33
Number of species observed: 160
Estimated number of species: 323
Average species density per 1000 m^2: 42

Diagnostic species: *Digitaria velutina*
Constant species: ***Aristida adscensionis***, ***Acacia mellifera* subsp. *detinens***, ***Kyphocarpa angustifolia***, ***Urochloa brachyura***, ***Pupalia lappacea***, *Grewia*

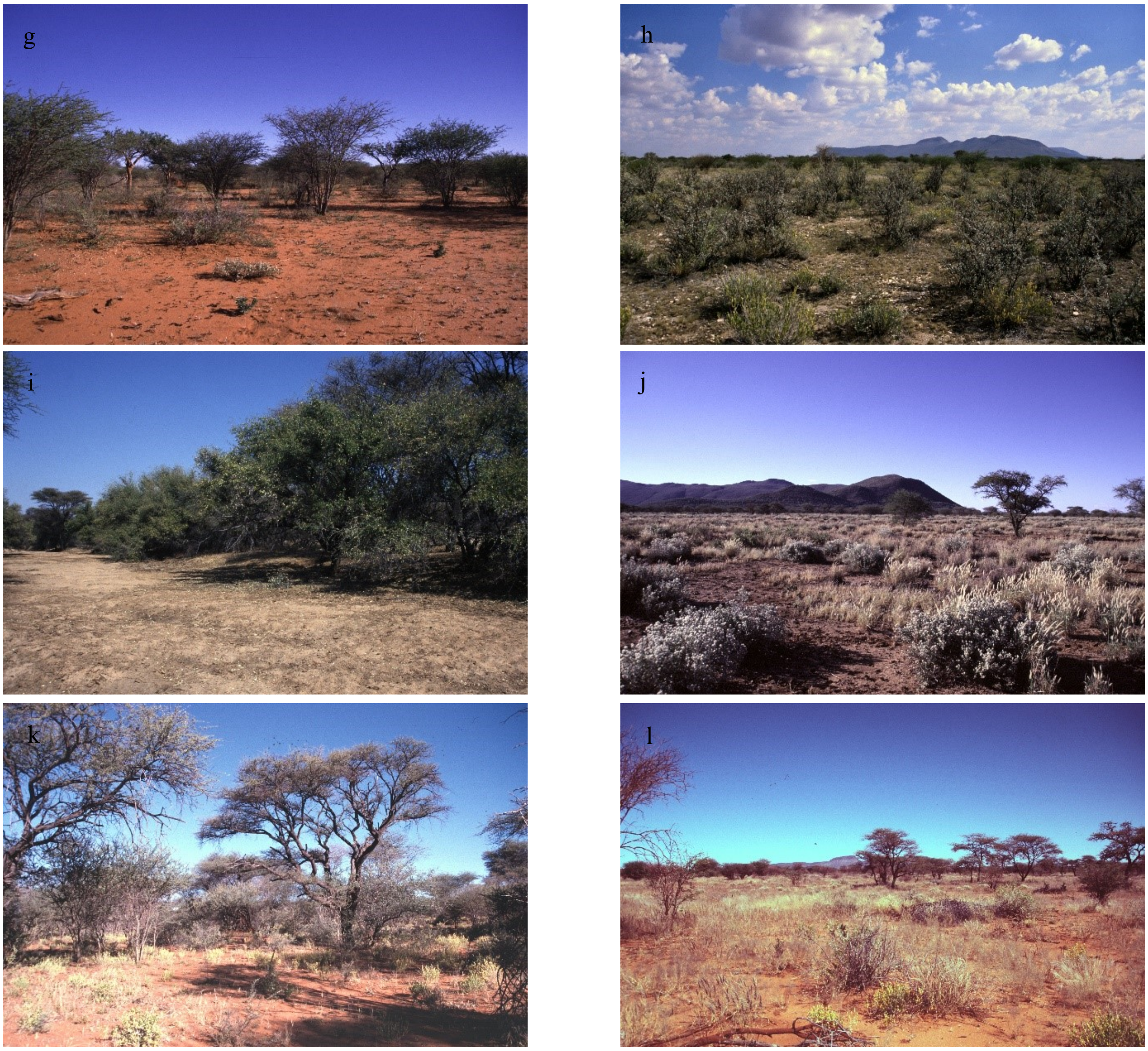

Figure 6 continued: *Typical views of the various associations. (g)* Acacia mellifera–Monechma genistifolium *association (relevé 854); (h)* Boscia foetida–Leucosphaera bainesii *association (relevé 760); (i)* Ziziphus mucronata–Acacia tortilis *association (relevé 782); (j)* Anthephora schinzii–Leucosphaera bainesii *association (relevé 898); (k)* Monechma genistifolium–Acacia tortilis *association in its closed form adjacent to the river floodplains (relevé 833); (l)* Monechma genistifolium–Acacia tortilis *association in its open form, away from the floodplains, transitioning to the plains habitats (relevé 816).*

flava, *Stipagrostis uniplumis* var. *uniplumis*, *Lycium eenii*, *Leucosphaera bainesii*, *Enneapogon cenchroides*, *Boscia albitrunca*, *Dichrostachys cinerea*, *Barleria lanceolata*, *Acacia tortilis* subsp. *heteracantha*, *Lycium bosciifolium*, *Talinum arnotii*, *Monechma genistifolium* subsp. *genistifolium*, *Eragrostis trichophora*

Dominant species: ***Acacia mellifera*** **subsp.** ***detinens***, ***Stipagrostis uniplumis*** **var.** ***uniplumis***, ***Monechma genistifolium*** **subsp.** ***genistifolium***, *Eragrostis porosa*, *Aristida adscensionis*, *Acacia tortilis* subsp. *heteracantha*, *Acacia hebeclada* subsp. *hebeclada*, *Ondetia linearis*, *Leucosphaera bainesii*, *Dichrostachys cinerea*, *Aristida rhiniochloa*, *Albizia anthelmintica*, *Acacia reficiens*

This vegetation forms a transition between the riparian thickets and associated floodplains, and the adjacent plains habitats. It is often an indicator for a degrading *omuramba* eroding to become an ephemeral river. Conspicuous is a gradual increase in trees, especially an increase of *Acacia tortilis* towards the riparian thickets on the riverbanks (Figures 6k and 6l). The structure varies accordingly from a tall, closed woodland to a tall, semi-open to bushland (Figure 5h).

Biodiversity indicators

The species richness per 1000 m^2, Shannon Index (H') and Simpson's Index (D) are depicted in Figure 7.

The narrow range of diversity for associations 1.1 and 1.2, and to a certain extent in 2.1 and 5.1, are likely a result of the low number of relevés sampled within these vegetation associations. The wide range of the lower quartile of Shannon Index as well as Simpson's Index data compared to the fairly compact upper three quartiles in most associations indicates a tendency for these associations to be encroached, dominated by a few phanerophytic species.

Environmental gradients

The NMS produced an ordination in three dimensions, with the final stress for the best solution being 17.920, and a final instability of 0.00000, after 95 iterations. The randomised data in the Monte Carlo test did not result in a stable solution after 249 iterations. The ordination graph is presented in Figure 8.

A great amount of overlap is evident between the various higher order syntaxonomic groupings (habitat types), indicative of the close relationship between the associations and the often ecotonal nature of these associations. There is however a clear split between the plains habitat (association 3.1 and 3.2) and the shallow calcareous soils associations (associations 4.1 and 4.2) visible along Axis 2. The

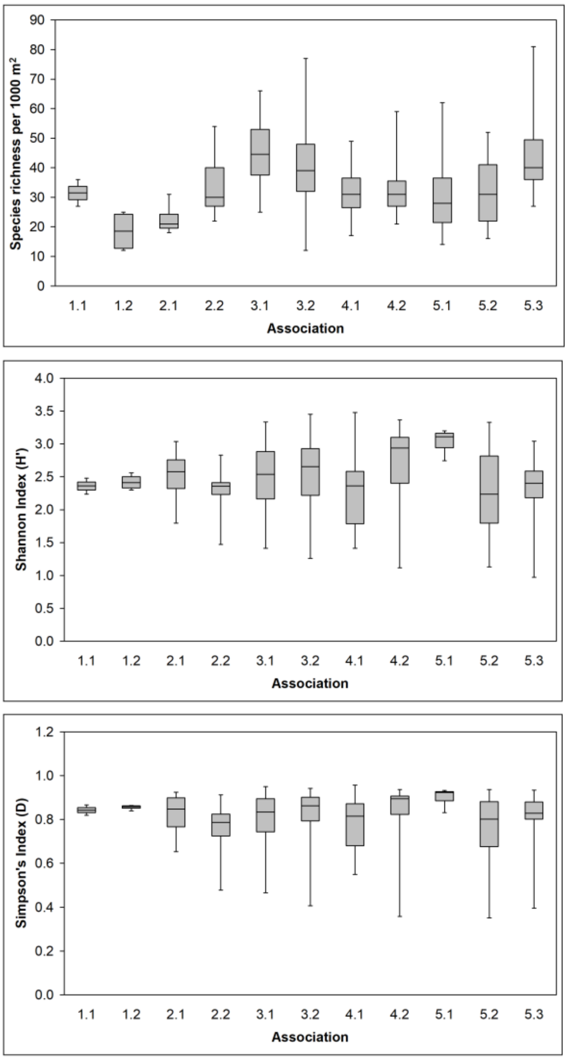

***Figure** 7: Diversity indicators for the various associations described. a) Species density per 1000 m^2; b) Shannon index and c) Simpson's Index*

main environmental drivers are the local topography along Axis 1, the soil pH as indicated by the proxy values along Axis 2, and the slope of the landscape along Axis 3. The vegetation reacts to these three main gradients by an increased number of shrubs towards the lower landscape positions (riverine habitats) as represented by Axis 1, a clear increase in dwarf shrubs along the pH gradient along Axis 2, and an increase in number of species and perennial grass cover towards the flatter landscapes, as indicated by Axis 3 (Figure 9).

Livestock Farming Suitability

Results for the Livestock Farming Suitability Index are presented in the graph in Figure 10. Detailed data and index values are presented in Online Appendix 3.

Typically, the suitability index has a maximum value of 2235. The following value-ratings have been set arbitrarily by Strohbach (2018):

- Unsuitable for livestock farming: <400
- Low potential for livestock farming: 400–800
- Moderate potential for livestock farming: 800–1200
- High potential for livestock farming: 1200–1600
- Very high potential for livestock farming: >1600

In all cases, the less a particular factor contributes to the farming suitability (or conversely, the more detrimental it is to livestock husbandry), the smaller is the portion of the bar for that particular factor. In this way the *Ziziphus mucronata–Dichanthium annulatum* association (1.1) scored a 'very high suitability' ranking due to its dense, perennial grass sward (as positive contributors) and little to no bush encroachment (as a detrimental contributor). Only the two plains habitat associations, the *Ondetia linearis–Acacia mellifera* association (3.1) and the *Aristida congesta–Acacia mellifera* association (3.2) are classed as having 'moderate suitability' for livestock farming, whilst all other associations are classed as 'low suitability' for livestock grazing. Key contributing factors are a high degree in bush encroachment (extreme in 2.1 and 5.1) as well as a fairly low grass cover, particular the low perennial grass cover. Only in the *Andropogon gayanus–Combretum apiculatum* association (2.1) no toxic species were found, which added to its potential suitability.

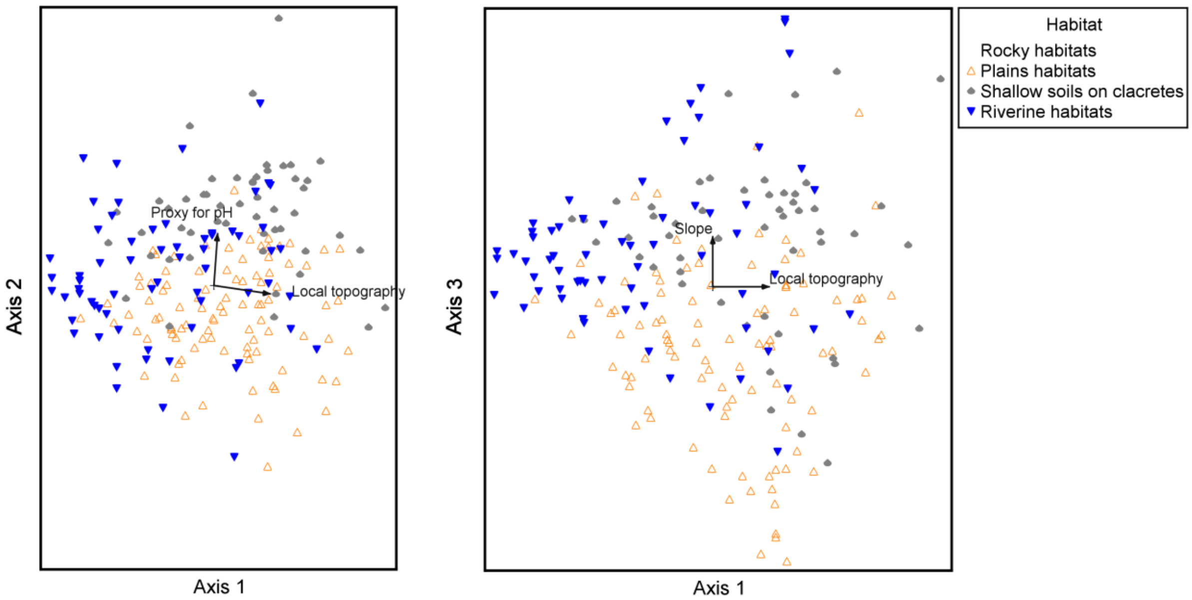

***Figure 8**: NMS ordination diagrams, indicating both the identified higher order syntaxonomic groupings (habitat types) and driving habitat gradients.*

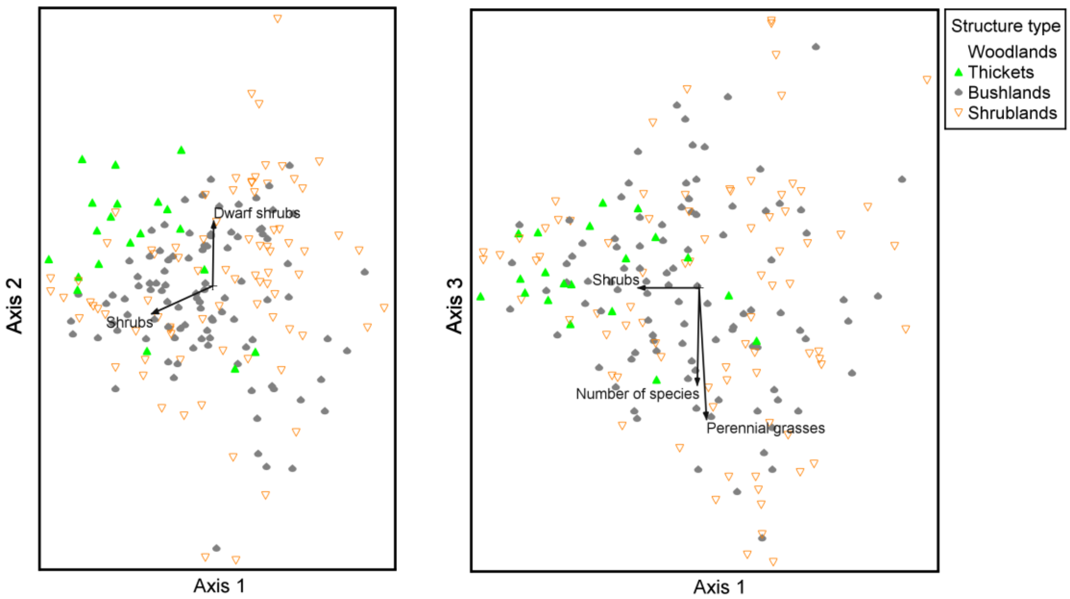

***Figure 9:** NMS ordination diagrams, indicating both the vegetation structure types and reaction of growth forms and biodiversity to the environmental gradients indicated in Figure 8.*

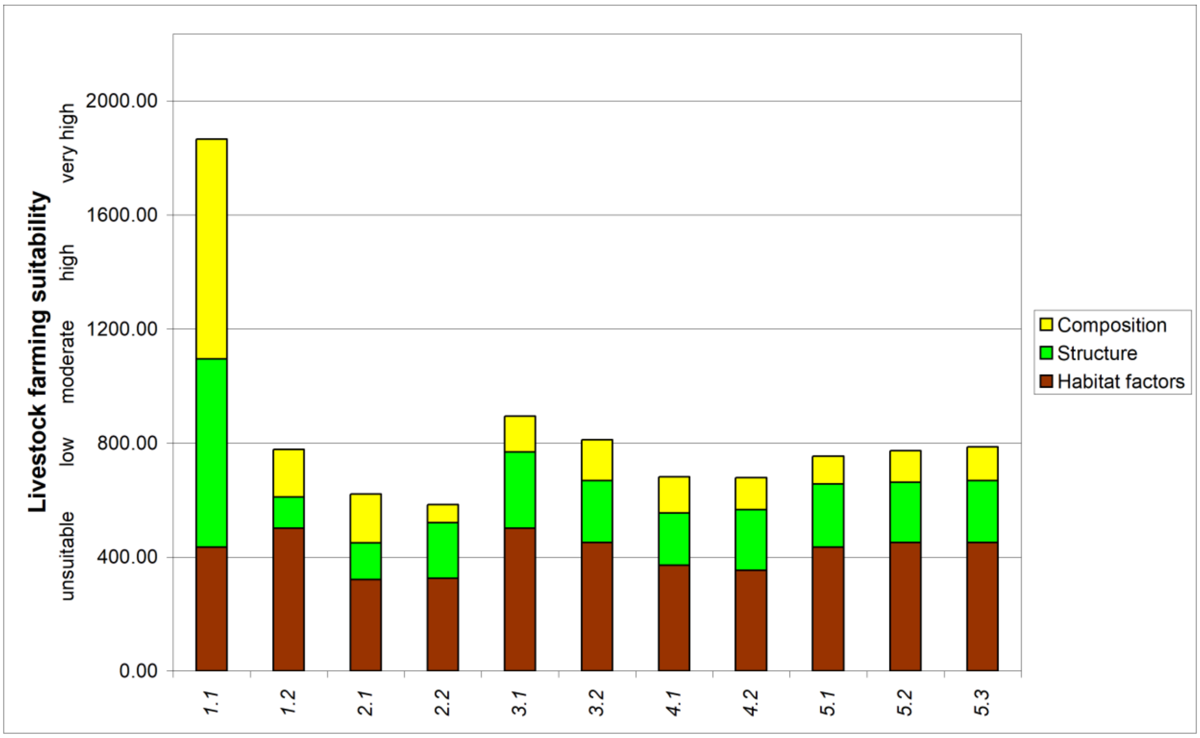

Figure 10*: Overall Livestock Farming Suitability Index for the vegetation associations of the farm Erichsfelde*

Vegetation map

The vegetation map is displayed in Figure 11, whilst a summary map of the Livestock Suitability Index is displayed in Figure 12. The areas covered by the different vegetation association within the study area are displayed in Table 3.

DISCUSSION AND CONCLUSION

Although five distinct higher order syntaxonomic classifications could be identified, these could only be assigned to broad habitats, but neither ranked nor named, due to the limited spatial nature of the available data set. A comparison to data collected by Strohbach (2002) and other subsequently collected data (as part of the GIVD AF-NA-001 – Strohbach & Kangombe 2012) will provide a better appreciation of the higher-order groupings.

The limitations of the present data set are also evident in the estimated number of species for each association. For most associations, less than half the estimated number of species have been observed, indicating a severe shortcoming in the data set. The observed number of species fall within the range (300 – 399) given by Mendelsohn et al. (2002), as derived from Craven (2001) for the area, whilst the estimated number of 449 species for the entire study area (using

Table 3: *Areas covered by the various vegetation associations on the Farm Erichsfelde in the Otjozondjupa Region*

Association	**Area (m²)**	**Area (ha)**
1.1 *Ziziphus mucronata–Dichanthium annulatum* association	43,949	4.4
1.2 *Marsilea–Leptochloa fusca* association	25,754	2. 6
2.1 *Andropogon gayanus–Combretum apiculatum* association	3,859	0.4
2.2 *Maerua parvifolia–Acacia erubescens* association	637,263	63.7
3.1 *Ondetia linearis–Acacia mellifera* association	10,273,240	1,027.3
3.2 *Aristida congesta–Acacia mellifera* association	770,39,434	7,703.9
4.1 *Acacia mellifera–Monechma genistifolium* association	12,394,779	1,239.5
4.2 *Boscia foetida–Leucosphaera bainesii* association	6,649,862	665.0
5.1 *Ziziphus mucronata–Acacia tortilis* association	2,091,025	209.1
5.2 *Anthephora schinzii–Leucosphaera bainesii* association	11,383,751	1,138.4
5.3 *Monechma genistifolium–Acacia tortilis* association	7,567,499	756.7
Farm dams	212,089	21.2

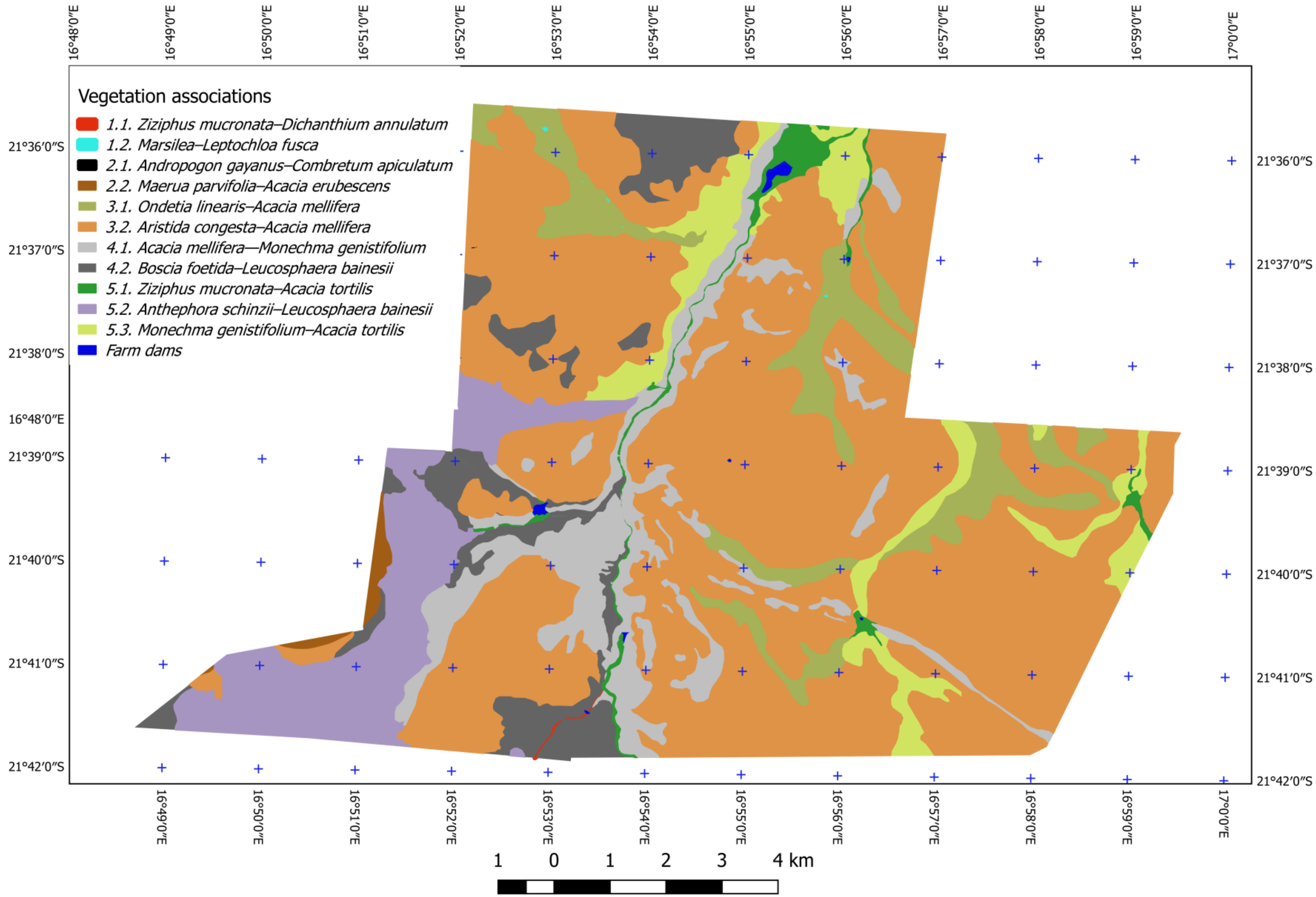

Figure 11: *Map of the vegetation associations described for Farm Erichsfelde.*

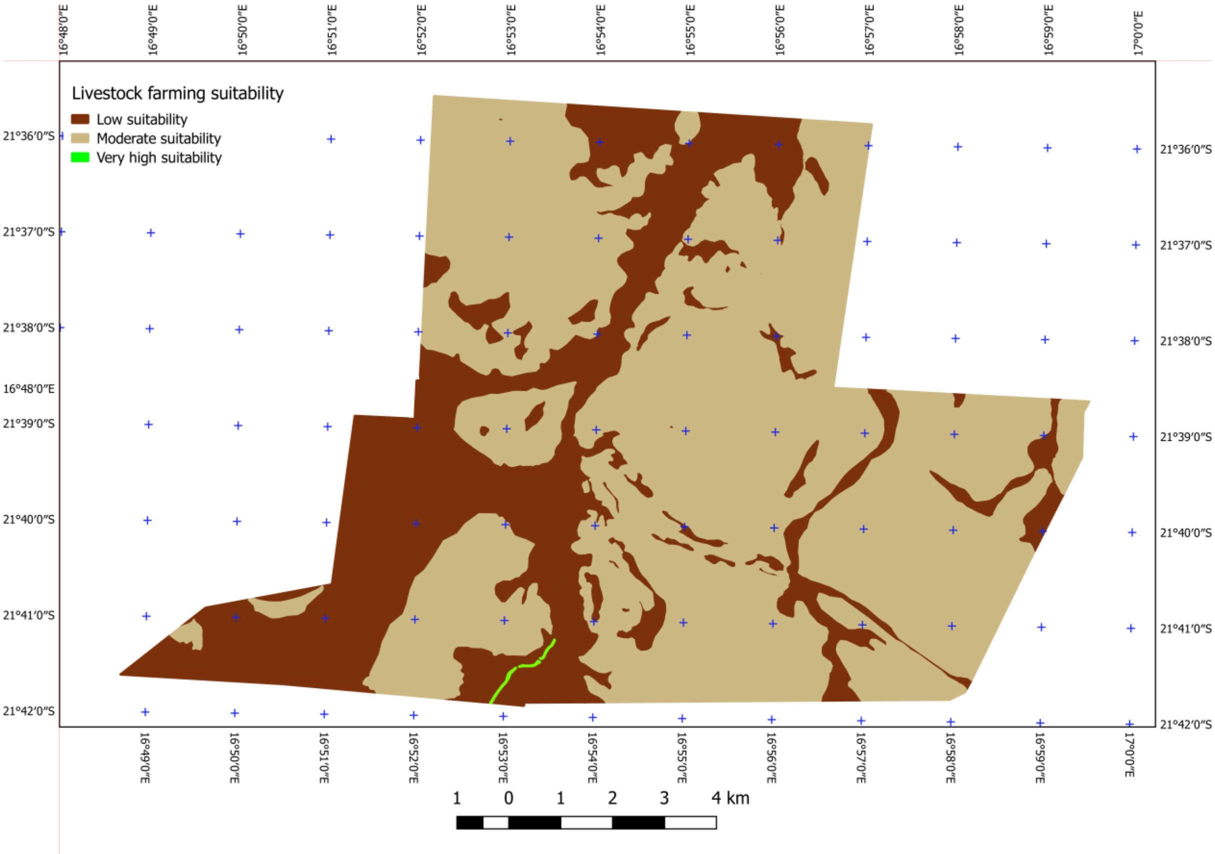

Figure 12: *Livestock farming suitability of the vegetation of Farm Erichsfelde, following the criteria described by Strohbach (2018).*

the first order Jackknife procedure) exceeds this number by far.

Grazing capacity especially for the semi-arid and arid regions, as is the case of central Namibia, is highly dependent on the often fluctuating rainfall. In the case of Erichsfelde, a CV of 44% of the long-term average since 1955 (352 mm) has been calculated (based on data supplied by the farm manager). Because of this high variability, no fixed grazing capacity (as provided e.g. within the Relative Homogenous Farming Areas report (Departement Landbou Tegniese Dienste 1979) can be determined. This problem has been highlighted by various authors before (Bester 1988, Lubbe 2005, Espach et al. 2006). For this reason the Livestock Suitability Index (Strohbach 2018) has been developed. This does not give a grazing capacity, but rather a Suitability Index based on the habitat, composition and structure of the vegetation. The calculated values indicate a reduction in suitability, if one considers that, in 1978, the vicinity of Erichsfelde was rated as the 'second best' farming area countrywide with a carrying capacity of 36 kg/ha. In relation, the highest class for the country was regarded as being able to carry 45 kg of live mass per ha, and the lowest only 4 kg/ha (Departement Landbou Tegniese Dienste 1979).

The main reason for the reduction in this suitability for livestock farming can be attributed to a steady increase in shrub and tree density ('bush encroachment') as well as a reduction in the density and quality of the grass sward (i.e. less high-value, perennial grasses, and a relative increase in low-value, annual grasses). Volk already commented on this in the 1960s (Volk 1966), whilst similar observations were made during recent studies (Jürgens et al. 2010 pp. 220–221). In particular, the *Ondetia linearis–Acacia mellifera* association (*omiramba*) were described by Volk in 1956 as nearly treeless, with a dense, perennial grass sward (Volk 1956), compared to the present-day tall, closed shrublands (Figures 4e and 5e). Similar ecosystems in the Highland Savanna were described as endangered by Volk & Leippert in 1971. This warning was confirmed by a recent study in the Auas-Oanob Conservancy in the Khomas Hochland that found these habitats to be eroded and/or encroached (Strohbach 2017).

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