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Human impacts on woody vegetation, and multivariate analysis: a case study based on data from Khowarib settlement, Kunene Region.

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Abstract

The effects of human and livestock utilisation on woody vegetation communities in close proximity to Khowarib settlement, Kunene Region, were assessed. Vegetation sampling of individuals of 2cm diameter was carried out using transects located in different topographic categories and at different distances from Khowarib. Species, branch removal, and height of browse line were recorded for each individual, while distance from the settlement and topographic category (reflecting substrate) were recorded for each sample. For purposes of analysis, values for branch removal and browse line were averaged for each sample and, together with distance from settlement, treated as measures of utilisation impact. Community data were related to the environmental variables, including the utilisation measures, using a suite of multivariate techniques, namely classification using the program TWINSPAN, and indirect and direct gradient analyses (Detrended and Canonical Correspondence Analyses), using the program CANOCO. This indicated a significant, but small-scale, negative impact of these use measures on the species richness of the samples. The study provides a focus for discussion regarding the appropriateness of such numerical analytical techniques in assessing human and livestock utilisation impacts on dryland vegetation. This is particularly relevant in the context of initiatives within Namibia to 'combat desertification', which are generally hampered by a lack of quantitative or standardised information concerning patterns and impacts of vegetation resource use, especially in communal farming areas.

Keywords: Sesfontein-Khowarib Basin, multivariate analysis, classification, ordination, gradient analysis, scale, degradation.

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Introduction

This paper is based on previously unpublished work conducted in Namibia in 1992 (see Sullivan, 1993a, 1993b). It is presented here in response to recent interest regarding the use of multivariate methods to explore and analyze community data from the pro-Namib and Semi-Desert Savanna Transition Zone, as identified by Giess (1971), (see, for example, Cowlishaw & Davies, forthcoming; Jürgens, 1995). More specifically, it addresses the advantages and disadvantages of this methodology as an appropriate tool for assessing vegetation degradation caused by human and livestock impacts in a dryland area. This is the focus for vegetation work currently being conducted by Sullivan in and around the so-called Sesfontein/Khowarib Basin on a much expanded data set.

Study area

Khowarib settlement (S 19°15', E 13°15') is situated on the southern bank of the ephemeral and westward-flowing Hoanib River, in west-central Kunene Region, formerly northern Damaraland (see Figure 1).

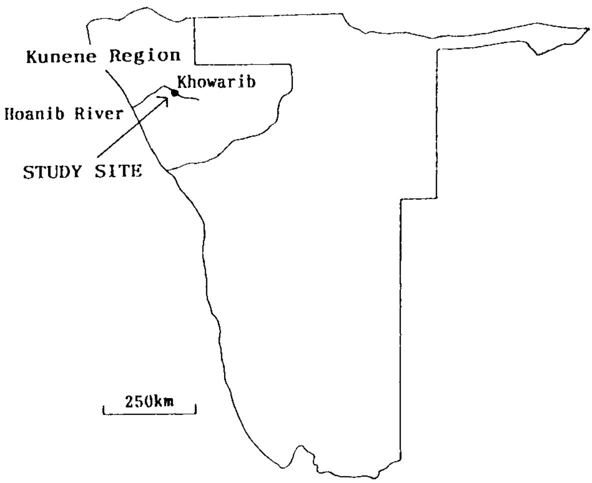

Figure 1: Map of Namibia indicating study area.

Climate

The single most important climatic feature of this area is its absolutely low rainfall and the associated unpredictability of this rainfall through time and space. Time series rainfall data* for the nearby settlement of Sesfontein for the years 1902-1913 and 1957-1986 has a Coefficient of Variation** of 71.24%. Following Noy-Meir (1973), Caughley (1987) and Ellis *et al.*, (1993), this high coefficient suggests that rainfall in this area, and ecological dynamics related to this, are better described by their variability than by average values.

Accompanying this low and variable rainfall are extremely high evapotranspiration rates, estimated as in the region of 2000-3000mm^{a-1} (Infoscience, 1994: 8). This combination of factors means that, as is characteristic for dryland areas, environmental productivity is primarily moisture, as opposed to, nutrient limited.

Temperatures are characterised by high diurnal and seasonal variations.

Topography

Khowarib is situated on the eastern edge of the so-called Transitional or Pro-Namib Plains between the Namib Desert proper to the west and the Interior Highlands to the East (cf. Mabbutt, 1952: 335-337). The Hoanib River is one of several westward flowing rivers traversing these morphological regions, and forms a deeply incised valley with many large tributaries. To the east of the settlement the Hoanib becomes constrained by the uplands of the interior plateau and this forms the steep slopes of the Khowarib 'Schlucht' or gorge. Complicated and rugged formations of dolomites, schists and calcrete are characteristic of the entrance into the Schlucht. West of the Khowarib settlement, however, stretch flat semi-desert plains of fertile alluvial sands and silts.

Vegetation*** *(see Appendix 1 for species author citations)*

The vegetation of Kunene can be described as extremely varied in structure, physiognomy and species distribution, reflecting diverse topographic factors and related soil and micro-climate characteristics. Floristically the area is normally considered part of the Karoo-Namib biogeographical Region, characterised by a high incidence of succulent life-forms (Werger, 1978a: 145-170, 1986; White, 1983). It is, however, highly individual having many taxa of the Sudano-Zambezian Region, particularly along wider ephemeral river valleys (Werger, 1978b: 234). These include *Ficus sycomorus*

* Rainfall data from the Weather Bureau, Windhoek; the Climate Research Unit, University of East Anglia; and the National Meteorological Library, London.

** i.e. the standard deviation expressed as a percentage of the mean.

*** Nomenclature follows the current species list of the National Botanical Research Institute (NBRI), Namibia. See also Kolberg, *et al.* (1992).

(Moraceae), *Plicosepalus kalachariensis* (Loranthaceae), *Acacia erioloba*, *Faidherbia albida*, and *Mundulea sericea* (Fabaceae), *Ziziphus mucronata* (Rhamnaceae), *Salvadora persica* (Salvadoraceae), *Grewia bicolor* (Tiliaceae), *Cordia sinensis* (Boraginaceae), *Sterculia quinqueloba* (Sterculiaceae), *Boscia albitrunca* (Capparaceae), and *Combretum apiculatum* and *C. imberbe* (Combretaceae) (Nordenstam, 1974: 57). Many of these are characteristic of the riparian forest supported by the Hoanib River.

Jürgens (1991: 21, 30-32) has redefined the area as the 'Damaraland-Kaokoland Domain' within his Nama-Karoo phytogeographical Region. Characteristic species include *Maerua schinzii* and *Boscia foetida* (Capparaceae), *Moringa ovalifolia* (Moringaceae), and *Euphorbia virosa* (Euphorbiaceae), while the numerous endemic or near-endemic elements include *Acacia robynsiana* and *A. montis-usti* (Fabaceae), *Commiphora giessi* and *C. kraeuseliana* (Burseraceae), and *Sesamothamnus guerichii* (Pedaliaceae).

Nordenstam (1974: 58) describes the 'Kaoko element' as an interesting phytogeographical group confined to southern Angola and north-west Namibia, comprised of well-defined species which can be considered as 'epibiotic relic elements'. Taxonomically isolated, monotypic genera include *Welwitschia* (Welwitschiaceae), *Phlyctidocarpa* (Apiaceae), and *Kaokochloa* (Poaceae). Other well-defined species with their phytogeographic centre north of the Brandberg include *Acacia robynsiana* (Fabaceae), *Balanites welwitschii*, and many *Petalidium* spp. (Acanthaceae). More than 25 species recorded by Nordenstam (1974: 60, 63) for the Brandberg Mountain, some distance south of Khowarib, are probably the remains of an old Afro-arid flora, and have a markedly disjunct distribution between the arid areas of both the Karroo-Namib region and the Sahalian-Oriental domain of the Sudano-Zambesian region, or in the adjacent Saharo-Sindian region.

According to Giess' Vegetation Map of Namibia Khowarib is located in the Mopane Savanna typical of the north-west, and characterised by *Colophospermum mopane* (Fabaceae) (1971: 9-10). This species occurs as a tree or shrub depending on local conditions and, with its relatively shallow root system, is able to compete in areas where moisture accumulates at shallow depth (cf. Cole, 1986: 116; Giess & Tinley, 1968: 251-252). Within this broad vegetation zone there is a wide variety of habitats, including a uniquely high diversity of the genus *Commiphora* (Burseraceae) on rocky substrates. A significant habitat in the Sesfontein-Khowarib Basin is the fertile alluvial sands and silts deposited by the Hoanib River and dominated by tall *Acacia tortilis* subsp. *heteracantha* (Fabaceae) savanna woodland.

Animal wildlife

The area is host to a high diversity of animal wildlife and is well-known for its desert-dwelling populations of elephant (*Loxodonta africana*), black rhino (*Diceros bicornis*), and the endemic Hartmann's zebra (*Equus zebra hartmannae*). Communal farmers in the area currently have no legal entitlement to these animal resources. The

Ministry of Environment and Tourism is, however, aiming to implement schemes which will confer use rights to animal wildlife by local people and thus facilitate income generation from wildlife (cf. Jones, 1993: 48).

Settlement and land use

It is likely that Khowarib, and more particularly the permanent spring in the Khowarib Schlucht, has been a focus for human habitation for millennia. It is currently settled by a predominantly Damara-speaking population who practise livestock herding, grow vegetables and grain crops (primarily maize and wheat) in an irrigated garden established by the previous administration, and who utilise indigenous vegetation resources for a variety of purposes (see below). Livestock are kraaled both at Khowarib itself, and at several satellite stockposts around the settlement (cf. van Warmelo, 1962: 37).

In recent historical times, the area has seen a continually shifting human population related primarily to two interrelated series of movements (cf. van Warmelo, 1962: 11; Malan, 1973: 83; Malan, 1974: 114; Hitzeroth, 1976: 188; Lau, 1987): the movement north of Nama and Oorlam Afrikaner commando groups who had firearms and horses through their trade relations with the Cape and who were thus able to illicit tribute in the form of livestock from Herero and Damara pastoralists; and the movement south by Herero pastoralists related first to their initial migration into north-west Namibia and latterly to their return to the area during this century and following their impoverishment due to Oorlam raiding tactics and the rinderpest epidemic of 1896-1897. Today the area is subject to a further influx of Herero pastoralists related to the new freedom of movement within Namibia's communal areas since Independence and following the extremely heavy rains of the 1994/1995 season.

Human history associated with land use in this area is thus multi-layered, resulting in the potential for conflicting claims to land and resources.

Vegetation use

Indigenous vegetation resources fulfil many subsistence needs at Khowarib providing important sources of food, household medicines and fuel, and the raw materials for building, household utensils and a variety of local industries. Many people have no access to alternative resources and these resources are thus of major, as opposed to supplementary, significance to people's livelihoods. In terms of resources from woody species utilised by the inhabitants, household survey information collected by these authors indicated that the products of some 37 species are used for a variety of purposes, as summarised in Table 1 (cf. Sullivan, 1993a: 40-45; Sullivan, 1993b: 28-33).

Table 1: Numbers of woody plant species recorded for different forms of utilisation at Khowarib settlement, Kunene region.	
type of utilisation	numbers of species recorded (total used = 37)
food: fruit resin	19: 12 7
household medicines	11
household utensils	10
leather dyes/tanning agents	6
browse for livestock	14

Objectives

This study had two main objectives:

1. To define the impact of human and livestock use on woody vegetation in the vicinity of a permanent settlement in a dryland area, using a variety of indicators (e.g. species diversity and composition, and relationships of these with environmental variables including measures of utilisation).

2. To assess the value of using multivariate analytical techniques in pursuit of objective 1; i.e. to explore and describe community data in relation to utilisation impacts, and to statistically test the relationships between particular communities and specific environmental variables or combinations of variables.

Methods

Field methods

Sampling strategy

In a semi-arid environment such as Kunene, indigenous perennial woody species, adapted to conditions of low and irregular rainfall, can act as longer-term indicators of environmental change caused by settlement impacts. The woody vegetation surrounding Khowarib was surveyed using a 'zig-zag' transect method (following Leithead, 1979: 29-30) (Figure 2). In this method each consecutive individual is sampled according to its proximity to the preceding individual, providing it is within

45° on either side of a stated compass-bearing from this individual. The strength of this technique lies in the fact that it makes no assumptions regarding density or distribution of species, the vegetation itself dictating the length of the transect. This feature of the technique is extremely relevant for surveying dryland vegetation where species distributions are characteristically patchy and dispersed.

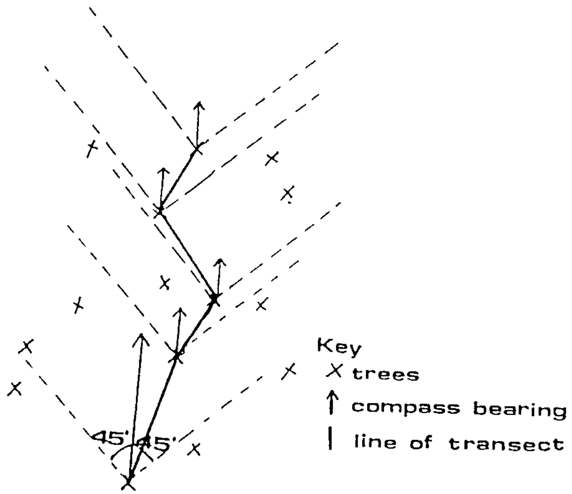

Figure 2: Schematic diagram of the 'zig-zag' transect sampling method (following Leithead, 1979).

In order to take into account the substantial changes in topography around Khowarib the area was split into three topographic categories based on geomorphological and plant physiognomic characteristics (cf. Cowlishaw & Davies, forthcoming: 4). These were sampled separately and at different distances from the settlement (Figure 3). The resulting stratified sample is described as follows (see Table 1 which summarises this information):

Plains:

The Khowarib settlement itself was situated within this topographic region and the vegetation sampled within the settlement therefore falls within this category. A total of 12 transects were carried out in the plains vegetation consisting of 4 within the settlement, 4 on the outskirts of the settlement and 4 located 5 km away from the settlement. Broadly speaking, these transects radiated out from the centre of the settlement.

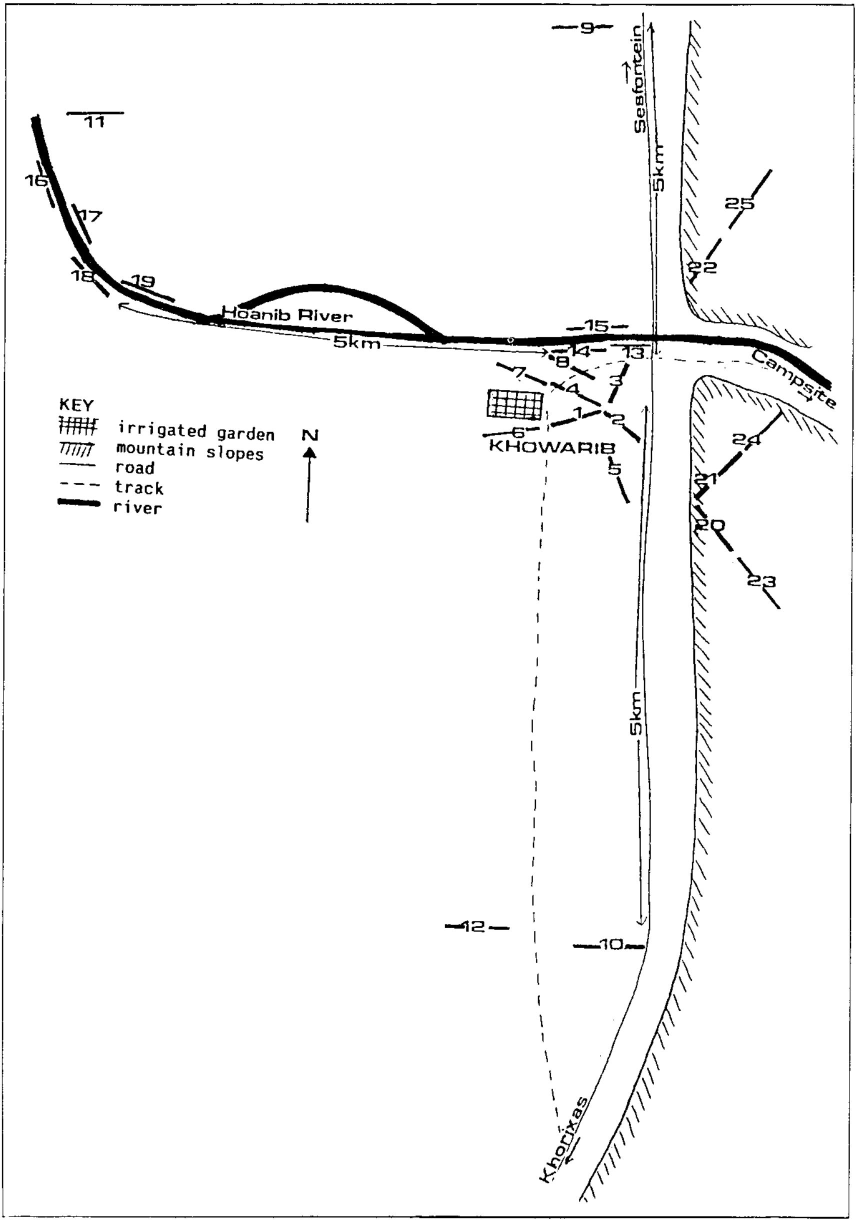

Figure 3: Sketch-map showing location of transects (1-12 = plains; 13-19 = riverine; 20-25 = mountain).

Riverine:

These transects were located on the alluvial banks of the Hoanib River. Seven transects were carried out in this category; 3 on the outskirts of the settlement and 4 located 5 km away from the settlement.

Mountain:

The eastern side of Khowarib is flanked by the mountains of the Interior Highlands which at this point constrain the Hoanib into the Khowarib Schlucht. Six shorter transects were located on these mountains, 3 on the lower slopes and 3 on the upper slopes. As these mountains rise dramatically to substantial heights it was thought that the effect of altitude could legitimately replace the effect of distance in this category.

In each transect in the **plains** and **riverine** categories approximately 30 individuals were sampled, while the **mountain** transects each contained a smaller sample of 15 individuals. A total of 635 individuals were sampled.

Table 2: Samples and individuals by topographic category and proximity to settlement.

Topographic category	Proximity to settlement	No. of transects	No. of individuals
Plains:		12	335
	within Khowarib	4 (1-4)	107
	outskirts	4 (5-8)	120
	5 km away	4 (9-12)	108
Riverine:		7	210
	outskirts	4 (13-16)	120
	5 km away	3 (17 - 19)	90
Mountains:		6	90
	lower slopes (near)	3 (20 - 22)	45
	upper slopes (far)	3 (23 - 25)	45
Totals:		25	635

Individual attributes

For each individual of 2cm diameter, the following attributes were recorded:

• the species was identified. Plant nomenclature follows the current species list of the NBRI species (see also Kolberg *et al.*, 1992). A full list of species and families recorded in this study, together with author citations, is presented in Appendix 1. Where species could not be identified to species level (only one incidence), the local Damara name is given to facilitate future identification. Assistance with species identification was provided by Ms G.L. Maggs of the National Herbarium, Windhoek.

Measures of human and livestock impact:

• the degree of branch removal or **lopping** for human use, identified by the occurrence of clean cut marks through the branches or main stem, was classified according to the following scale:

0	no lopping
1	slight lopping; 1-2 large branches or only small ones removed
2	moderate lopping; 25-50% of branches removed
3	severe lopping; > 50% of branches removed
4	cut through the main stem/s so that the height of the tree was substantially reduced

• the height of the **browse line**, when one could be easily discerned, was measured.

Analysis

A suite of exploratory and analytical techniques were used to assess the relationship between the species diversity and composition of each sample, and the physical location and average utilisation measures recorded as 'environmental variables' for each sample.

Classification

The data set was used for the construction of a samples-by-species matrix, presented in Table 3, which was 'classified' using the TWINSPAN (Two-Way Indicator Species Analysis) program (Hill, 1979b). This is a polythetic divisive classification technique which uses information on all the species data to successively divide the samples into a hierarchy of smaller and smaller groups based on indicator species and floristics (Goldsmith *et al.*, 1986: 494). In TWINSPAN the data are first ordinated by reciprocal averaging and the samples are divided or polarised through emphasizing the species that characterise extremes on the reciprocal averaging axes (Gauch, 1982: 201-2).The values presented in the resulting table are new values or 'pseudospecies' based on levels of abundance for each species in each sample.

Table 3. Original samples-by-species data matrix constructed for TWINSPAN classification, DCA ordination and CCA applications.

Species	Samples																							
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Acacia erioloba	-	-	-	1	-	-	1	-	-	-	4	-	1	2	-	1	6	4	5	-	-	-	-	-	-
Acacia senegal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	2	-	-
Acacia tortilis	26	28	21	24	22	6	12	21	-	-	4	5	5	23	8	1	3	3	1	1	-	-	1	-	-
Boscia albitrunca	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Boscia foetida	-	-	-	1	3	-	-	-	-	1	-	3	-	-	-	-	-	-	-	1	2	2	1	2	1
Catophractes alexandri	-	-	-	-	-	-	-	-	-	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Ceraria longipedunculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Colophospermum mopane	-	-	9	2	-	-	-	5	22	-	11	5	22	-	12	2	-	-	1	-	2	8	-	-	-
Combretum apiculatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
Combretum wattii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	7	7	4	-	-	-	-	-	-
Commiphora multijuga	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	3	-
Commiphora pyracanthoides	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Commiphora virgata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Commiphora sp. (/aba/hub)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Faidherbia albida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	8	5	-	-	-	-	-	-
Gossypium cf. *anomalum*	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Lycium[5] sp.	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maerua schinzii	1	-	-	-	1	3	-	1	2	2	-	4	-	2	2	1	-	-	-	-	-	-	-	-	-
Pechuel-loeschea leubnitziae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-
Salvadora persica	-	1	-	-	4	16	17	3	6	-	11	9	2	3	5	22	12	8	9	-	-	-	-	-	-
Tamarix usneoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Terminalia prunioides	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	12	10	5	9	8	2

Recent fieldwork indicates that **/aba/hub** is *Commiphora glaucescens* (Sullivan, pers. obs.).
The Genus *Lycium* is under taxonomic revision.

Ordination: Detrended Correspondence Analysis (DCA)

Ordination techniques are multivariate methods which organise community data on the basis of species abundance by arranging species and samples in a low-dimensional space such that similar species and samples are close together and vice versa (Gauch, 1982: 109, 115; Gaillard *et al.*, 1992: 7). The reduction of multi-dimensional data to a low-dimensional space (i.e. 2-3 dimensions) is possible because other dimensions or axes are normally correlated with the most influential axes and, therefore, the location of species and samples along these axes is likely to reflect the underlying structure of the data (Gauch, 1982: 116). Relationships between community patterns and known environmental variables can then be inferred to produce an ecological interpretation of the community data, which can be tested using other methods. As such, ordination is an indirect gradient analysis method from which species-environment relationships can be explored and described in a qualitative manner (ter Braak, 1986: 1167).

Detrended correspondence analysis (DCA) is an ordination technique which assumes the unimodal distribution of the data and from which, by using weighted averages for both samples and species, relationships between the two can be inferred. It can be used to produce a spatial arrangement of samples and species along axes generated by the vegetation data such that their position reflects their similarity (Dudzinski & Arnold, 1973: 905; Goldsmith *et al.*, 1986: 501-2; ter Braak, 1986: 1167). Detrended Correspondence Analysis was applied to the samples-by-species matrix derived from the Khowarib vegetation data set (Table 2) using the computer program CANOCO 3.12 (ter Braak, 1991) which performs partial, detrended and canonical correspondence analyses (CCA). This program is an extension of the Cornell Ecology program DECORANA which is used for DCA and reciprocal averaging (Hill, 1979a).

Canonical Correspondence Analysis (CCA)

CCA, applied using CANOCO 3.12, is a relatively new multivariate analysis technique developed by ter Braak and designed to directly relate community composition to environmental variables. This is achieved by finding the ordination axes which reveal to the greatest possible extent the common structure of both the samples-by-species and samples-by-environmental variables matrices (presented in Tables 3 and 4) (Gauch, 1982: 163; ter Braak, 1986: 1167; ter Braak, 1987a). It is an extension of ordination techniques such as DCA which extract continuous axes of variation from species abundance data which can then be interpreted in the light of data concerning known environmental variables (ter Braak, 1986: 1167). Canonical ordination such as CCA, combines both ordination and regression to produce a **multivariate direct gradient analysis** of the relationships between a number of species and environmental variables (ter Braak, 1986: 1167; ter Braak, 1988: 159).

CCA analyses were applied to both the complete data set and a reduced data set from which the mountain samples had been removed, for reasons explained in the results section below.

In the ordination diagrams constructed from the CCAs the species and sites are represented as points (except for the second CCA analysis where distance is treated as ordinal) and the environmental variables as vectors portrayed in two ways: as arrows if the variable is ordinal or continuous, or by points if the variable is nominal or dichotomous (ter Braak, 1986: 1167). In the case of ordinal variables, environmental information is expressed by the directions and relative lengths of the representative arrows. The strength of the variable is related to length of the arrow with the

Table 4: Original matrix of samples-by-environmental measurements used in Canonical Correspondence Analysis (CCA).

Environmental variables	Samples 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
NOMINAL VARIABLES:																									
<u>Location:</u>																									
plains (1/0)	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
riverine (1/0)	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0
mountain (1/0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
ORDINAL VARIABLES (See key below):																									
<u>Distance:</u>																									
plains and riverine (0-2)	0	0	0	0	1	1	1	1	2	2	2	2	1	1	1	2	2	2	2	-	-	-	-	-	-
mountain (0-1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	1	1	1
<u>Impact measurements:</u>																									
lopping (0-4)	3	3	2	2	0	2	3	2	1	0	0	0	4	0	2	1	0	0	0	3	4	2	1	2	1
browsing (0-4)	3	3	4	3	1	2	1	3	0	0	0	3	3	3	2	0	0	0	2	2	3	3	0	0	0

<u>Key for ordinal variables</u>

DISTANCE:

plains and riverine: 0 - in settlement
1 - outskirts of settlement
2 - 5km from settlement

mountain: 0 - lower slopes
1 - upper slopes

IMPACT MEASUREMENTS:

lopping: 0 = 0
1 = <0.1 (average sample value)
2 = 0.2-1
3 = 1.01-1.5
4 = 1.5 -2

browsing: 0 = 0
1 = <1m (average browse-line for sample)
2 = 1 -1.1m
3 = 1.1-1.5m
4 = >1.5m

position of the arrowhead determined by the eigenvalues of the axes and the intraset correlations of that variable with the axes. As such, the length of the arrow is a measure of how much species change is accounted for by that variable. This means that the more important variables (i.e. those with higher eigenvalues) are represented by longer arrows. Nominal environmental variables, on the other hand, are represented by points located at the centroid (i.e. weighted average) of the sites belonging to that environmental class. The completed ordination diagram, therefore, shows visually the dominant patterns in the community produced by the relationship of species and sites to the environmental variables.

In the Khowarib vegetation data set the environmental variables were treated as follows: lopping and browsing are ordinal variables and are, therefore, depicted as arrows whereas the location of the samples in the plains, riverine and mountain topographic categories and at different distances from the settlement are nominal variables and are represented as points.

Testing of specific hypotheses: Monte Carlo permutation testing and partial CCA

Using the program CANOCO, specific hypotheses were tested concerning the influence of particular environmental variables on the vegetation community. These tests rely on the forward selection of environmental variables by Monte Carlo permutation tests, in this case using the default selection of 99 permutations (Ter Braak, 1988: 159; Gaillard *et al.*, 1992: 7). The data are thus considered analogous to experimental data; each environmental variable is viewed as a 'treatment' imposed on the vegetation, and the resulting community pattern is the 'response' to this treatment (Gaillard *et al.*, 1992: 9). In doing this, the percentage of variation in species abundance that can be attributed to a particular variable is revealed as the probability of that variable contributing significantly to the assemblage after a number of permutations (Gaillard *et al.*, 1992: 7). To overcome the problem of close association between variables a partial CCA can be applied so that the effect of 'background' variables are statistically partialled out as covariables, and the significance of a particular variable in its effect on the vegetation assemblage can be tested statistically (ter Braak, 1987b: 557; ter Braak, 1988: 159; Gaillard *et al.*, 1992: 9).

This analytical method was used to test the null hypotheses that there was no significant difference in species assemblages in samples with differing:

i. intensities of lopping
ii. intensities of browsing
iii. distances from the Khowarib settlement

Results

Classification

The results of the TWINSPAN classification are represented by an ordered two-way table of the original data (Table 5).

As can be seen from Table 5 and Figure 4, TWINSPAN classified the Damara samples into three major sample groups. These did not correspond exactly to the three known topographic categories, thus indicating that species composition and abundance were reflecting other underlying external variables. The three TWINSPAN groups were as follows:

Group 1

Acacia tortilis is the indicator species for this group which is represented by plains samples at all distances from Khowarib and **riverine samples near to Khowarib**. The **plains samples within Khowarib** have the highest weighted averages for *A. tortilis*.

Table 5: Ordered two-way table of the original samples-by-species matrix produced by TWINSPAN classification. TWINSPAN species abundance levels for each sample are as follows:

level 1 = 0-2 individuals of a species in the sample
2 = 3-5
3 = 6-10
4 = 11-20
5 = > 20

Species	Samples: values = TWINSPAN abundance levels																									spp. divisions
	16	17	18	19	12	06	09	11	13	15	07	01	02	05	14	03	04	08	20	23	24	21	22	10	25	1234
Faidherbia albida	-	2	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0000
Acacia erioloba	1	2	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0000
Combretum wattii	2	3	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0000
Pechuel-loeschea leubnitziae	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0000
Salvadora persica	5	4	3	3	3	4	3	4	2	3	4	-	1	2	2	-	-	2	-	-	-	-	-	-	-	0001
Acacia tortilis	1	2	2	1	3	3	-	2	3	3	4	5	5	5	5	5	5	5	1	1	-	-	-	-	-	0010
Boscia albitrunca	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0011
Gossypium cf. anomalum	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0011
Lycium sp.	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0011
Tamarix usneoides	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0011
Colophospermum mopane	2	-	-	1	3	-	5	4	5	4	-	-	-	-	-	3	2	3	-	-	-	2	3	-	-	01
Maerua schinzii	1	-	-	-	2	2	2	-	-	2	-	1	-	1	2	-	-	1	-	-	-	-	-	2	-	01
Boscia foetida	-	-	-	-	2	-	-	-	-	-	-	-	-	2	-	-	1	-	1	1	2	2	2	1	1	100
Acacia senegal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	1010
Commiphora multijuga	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	1	-	-	-	1010
Ceraria longipedunculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1010
Terminalia prunioides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	3	3	4	3	3	2	1010
Commiphora virgata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1011
Catophractes alexandri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	1	11
Combretum apiculatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	11
Commiphora pyracanthoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	11
Commiphora sp. (/aba/hub)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	11
sample divisions:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	
																			GROUP 2							
	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	
	GROUP 3				GROUP 1																					
					0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1			
					SUB-GROUP 1B						SUB-GROUP 1A															
					0	1	1	1	1	1	0	0	0	0	0	1	1	1								
						0	1	1	1	1	0	1	1	1	1											

Also characteristic of this group are *Salvadora persica*, *Colophospermum mopane* and, to a lesser degree, *Acacia erioloba*, *Maerua schinzii* and *Boscia foetida*.

The third TWINSPAN division splits group 1 into two sub-groups. Sub-group 1a contain all the **plains** samples from **within Khowarib**, most of the **plains** samples from the **outskirts of Khowarib** and one **near Khowarib riverine sample**, while sub-group 1b contains most of the remaining **plains outskirts** and **5 km away** samples and two **riverine** samples from the **outskirts** of the settlement. Sub-group 1a is thus dominated particularly strongly by *A. tortilis* and, with only 6 species found in 8 samples, has a generally lower species diversity than sub-group 1b with 10 species recorded in only 6 samples. This indicates that distance from the settlement was

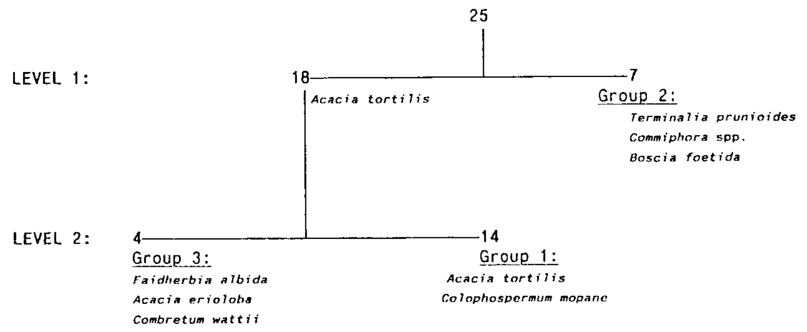

Figure 4: Dendrogram derived from TWINSPAN classification of the Khowarib data set. The 3 major divisions are indicated, together with the number of samples and dominant species in each division.

having an effect on the species composition of these **plains** and **riverine** samples which was independent of the topographic habitat divisions. A correlate of this effect was reduced species diversity with increased proximity to the settlement.

Group 2

This is a very well-defined group characterised by *Terminalia prunioides* and, to a lesser extent, *Boscia foetida* and *Acacia senegal.* These samples represent those located in the mountain topographic category and this appears to be the major underlying factor determining species composition in this group. The exception to this is sample 10 which is a **plains** sample located **5 km from Khowarib**.

Group 3

This group is characterised by high levels of *Salvadora persica*, with *Combretum wattii* and *Faidherbia albida* exclusive to this group and *Acacia erioloba* another important species. This group contains only the four **riverine** samples located **5 km from Khowarib** and, therefore, indicates that distance from the settlement was having a strong effect on species composition in the riverine samples. Not only was species richness slightly higher in the samples **5 km away** from the settlement but the composition itself was very different with two species which are relatively dominant in this group, *C. wattii* and *F. albida*, recorded only at this site.

Detrended Correspondence Analysis (DCA)

When DCA was applied to the Damara vegetation data set it was apparent that, while the overall variation was high (gradient length or sum of eigenvalues = 4.17), a considerable amount of the variation in the data could be explained by the first two axes constructed to fit the data. Axis 1, for example, had an eigenvalue of .872 and accounted for 20.9% variance of the vegetation data while axis 2 had an eigenvalue of .313 and thus the cumulative percentage variance accounted for by these two axes was 28.4%.

When the ordination scores for species and samples were listed in order of their position on axis 1 it was possible to detect some pattern in their ranks (Table 6). Broadly speaking, the first four ranked samples (transects 16-19) are those which occurred in the **riverine** vegetation **5 km away** from the Khowarib, thus indicating similarity in the composition of these samples. These are followed by a combination of **plains** samples at all distances from the settlement (1-9, 11, 12) and **riverine** samples **close** to the settlement (13-15). The fact that the **riverine** samples **5 km away** from Khowarib occur closely together and are separated in rank from the **riverine** samples **near** Khowarib suggests that there were factors associated with distance from the settlement that were affecting species composition independently of other environmental constraints. Like the **riverine** samples **5 km** from the settlement, the six mountain samples (20-25) also occur very closely together in rank, separated only by one **plains** sample (10) from **5 km** outside Khowarib which appears to be an atypical sample in terms of these ranked scores.

The species ranks follow this pattern with species associated with the **riverine** samples from **5 km** outside the settlement (e.g. *F. albida* and *Combretum wattii*) ranked closely together at one end of the spectrum, followed by a broad group of species found in both **plains** samples at all distances from the settlement and **riverine** samples **near** the settlement (e.g. *Acacia tortilis*, *Colophospermum mopane* and *Salvadora persica*), and completed by species such as *Terminalia prunioides* and *Commiphora* spp. associated with **mountain** samples.

The combined presentation of the DCA ranked sample and species weighted averages in an arranged matrix as in Table 6, reveals, in the concentration of larger values along the matrix diagonal, the underlying pattern in the community data described above.

The graphical presentation of the DCA ordination and the TWINSPAN classification groups described above is shown in Figure 5 in which the three outlined communities correspond with the TWINSPAN groups described above. From this it is apparent that group 2 is very distinct in terms of its characteristic species composition whereas groups 1 and 3 are more similar and can be considered to follow a gradient or continuum of variation in species composition.

Table 6: Ranked scores for samples and species in relation to the axis 1 ordination scores produced by detrended correspondence analysis. (The relationship between sample scores and the groups produced by TWINSPAN classification as described above is indicated).

Sample TWINSPAN Groups	Sample	ranked Axis 1 scores	Species	ranked Axis 1 scores
3	18	.0000	*Pechuel-Loeschea leubnitziae*	-.9237
3	19	.0138	*Faidherbia albida*	-.9087
3	17	.2996	*Combretum wattii*	-.6696
3	16	.9004	*Acacia erioloba*	.0510
1	07	1.1395	*Lycium* sp.	.7786
1	06	1.2297	*Salvadora persica*	.8583
1	11	1.5093	*Acacia tortilis*	1.6287
1	14	1.5489	*Tamarix usneoides*	1.8495
1	02	1.6030	*Colophospermum mopane*	2.6473
1	01	1.6856	*Boscia albitrunca*	2.6991
1	04	1.7225	*Gossypium anomalum*	2.6991
1	08	1.7726	*Maerua schinzii*	3.1646
1	05	1.7938	*Boscia foetida*	3.7947
1	03	1.9343	*Terminalia prunioides*	4.5622
1	15	2.0322	*Acacia senegal*	4.6332
1	12	2.1315	*Commiphora multijuga*	4.7185
1	13	2.2717	*Ceraria longipedunculata*	4.9276
2	09	2.3240	*Commiphora pyracanthoides*	5.2316
2	22	3.4386	*Catophractes alexandri*	5.3118
2	21	4.2150	*Commiphora virgata*	5.7234
2	20	4.3202	*Combretum apiculatum*	6.3973
2	23	4.3458	*Commiphora* sp. (/aba/hub)	6.3973
2	24	4.5929		
2	10	4.9262		
2	25	5.8618		

Two samples can be considered outliers of the groups described above. First, sample 10, which is located in the plains habitat 5 km from Khowarib, is atypical of the other **plains** samples located **5 km from Khowarib** due to its extremely high value for *Catophractes alexandri*, which is only found at one other **mountain** sample. It also has a relatively high value for *Terminalia prunioides*, a species representative of the **mountain** samples. Sample 10 was located in closer proximity to the mountain slopes than the other **plains** samples (see Figure 3) and it is probably a higher incidence of rocky dolomite that is responsible for its floristic similarity with the **mountain** samples. Second, sample 25, an **upper slope mountain** sample, is the only sample contain-

Table 7. Arranged matrix of samples-by-species abundances based on DCA axis 1 scores.

Species	Samples: values = numbers of individuals in each sample																							
	18	19	17	16	07	06	11	14	02	01	04	08	05	03	15	12	13	09	22	21	20	23	24	10	25
Pechuel-loeschea leubnitziae	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Faidherbia albida	8	5	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Combretum wattii	7	4	7	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia erioloba	4	5	6	1	1	-	4	2	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Lycium sp.	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salvadora persica	8	9	12	22	17	16	11	3	1	-	-	3	4	-	5	9	2	6	-	-	-	-	-	-	-
Acacia tortilis	3	1	3	1	12	6	4	23	21	26	24	21	22	21	8	5	5	-	-	-	1	1	-	-	-
Tamarix usneoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Colophospermum mopane	-	1	-	2	-	-	4	-	-	-	2	5	-	9	12	5	22	22	8	2	-	-	-	-	-
Boscia albitrunca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Gossypium anomalum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-
Maerua schinzii	-	-	-	1	-	3	-	2	-	1	-	1	1	-	2	4	-	2	-	-	-	-	-	2	-
Boscia foetida	-	-	-	-	-	-	-	-	-	-	1	-	3	-	-	3	-	-	2	2	1	1	2	1	1
Terminalia prunioides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	10	12	9	8	5	2
Acacia senegal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-
Commiphora multijuga	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	3	-	-
Ceraria longipedunculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Commiphora pyracanthoides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Catophractes alexandri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	1
Commiphora virgata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Combretum apiculatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
Commiphora sp. (/aba/hub)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

ing two species, *Combretum apiculatum* and *Commiphora* sp. (**/aba/hub**), the former at relatively high levels.

Canonical Correspondence Analysis (CCA)

The CCA of the data set, indicating the direct relationship between the environmental and both sample and species data, validated the inferences drawn from both the TWINSPAN classification and DCA of the data set.

Analysis 1:

When CCA was applied to the full data set, the axes constructed indicated a strong division within the samples and species (Figures 6a and 6b). Axis 1, explaining 18.3% of variance in the species data and 38.2% of variance in the relationship between species and environmental variables, can be attributed to the strong effect of the mountain topographic category on species composition. It is this axis that explains the graphical separation between mountain samples and plains and riverine samples shown in Figure 6a. Axis 2, on the other hand, is represented by significant negative

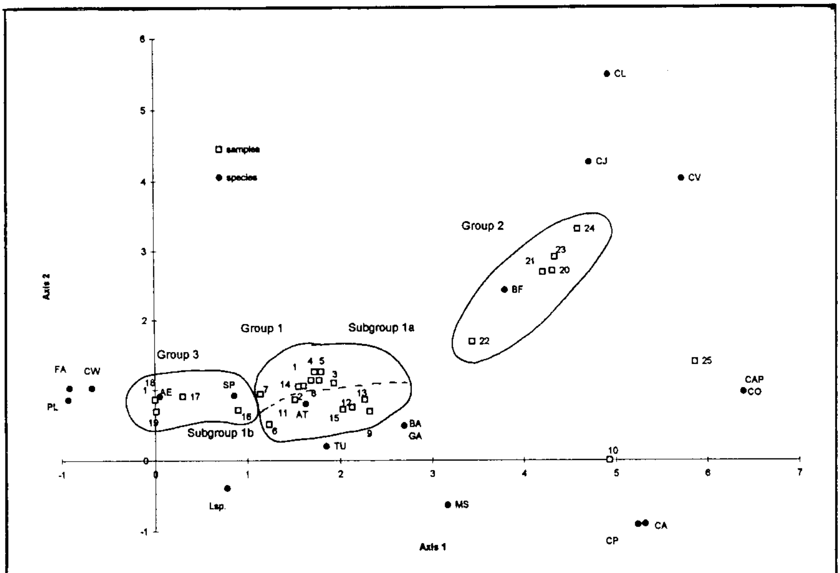

Figure 5: Ordination diagram of Detrended Correspondence Analysis (DCA) with TWINSPAN classification groups.

Key:

FA= *Faidherbia albida*; CW= *Combretum wattii*; PL= *Pechuel-Loeschea leubnitziae*; AE= *Acacia erioloba*; Lsp.= *Lycium* sp.; AT= *Acacia tortilis*; TU= *Tamarix usneoides*; CM= *Colophospermum mopane*; BA= *Boscia albitrunca*; CA= *Catophractes alexandri*; GA= *Gossypium anomalum*; MS= *Maerua schinzii*; BF= *Boscia foetida*; CJ= *Commiphora multijuga*; CL= *Ceraria longipedunculata*; CP= *Commiphora pyracanthoides*; CAP= *Combretum apiculatum*; CV= *Commiphora virgata*; CO= *Commiphora* sp. (/aba/hub).

values for the effects of lopping and browsing, and these values are reflected in the figures for the effect of distance from the settlement. This axis explains a cumulative percentage variance of 30% of the species data and 62.4% of the variation in the relationship between species and the environmental variables. Table 7 shows the axis 1 and 2 figures for the weighted correlation matrix from which the ordination diagram is constructed. Although the composition of samples 20-25 was primarily determined by their mountain location, the CCA does suggest some impact of human and animal utilisation by placing samples from the lower slopes, i.e. those nearest to the settlement, closer to the vectors representing human and animal impact.

Despite the slightly stronger effect of browsing, the direction and length of the arrows representing both browsing and lopping are similar thus indicating that they were having corresponding effects on the vegetation surrounding Khowarib. These arrows extend in the opposite direction to the location of the centroid representing the furthest distance from the settlement (Figure 6c), thereby indicating that, as would be

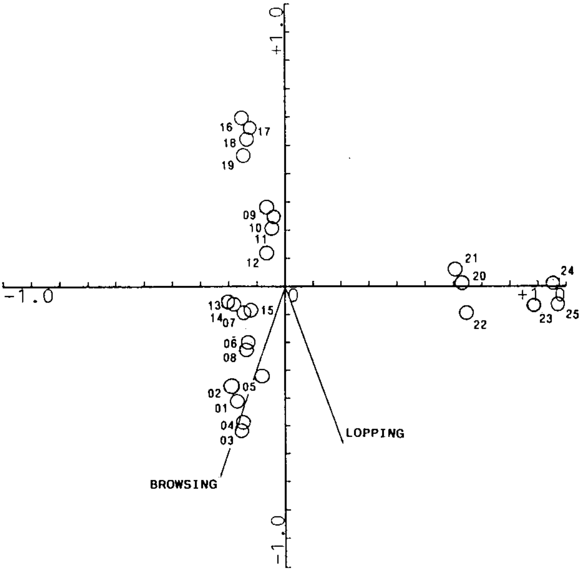

Figure 6a: Sample ordination

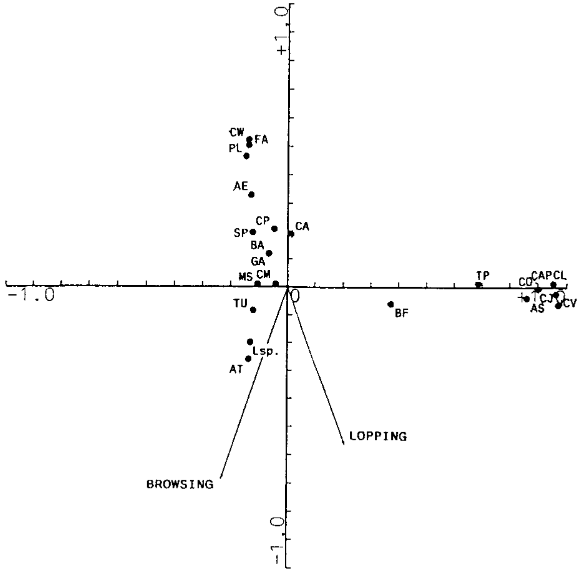

Figure 6b: Species ordination

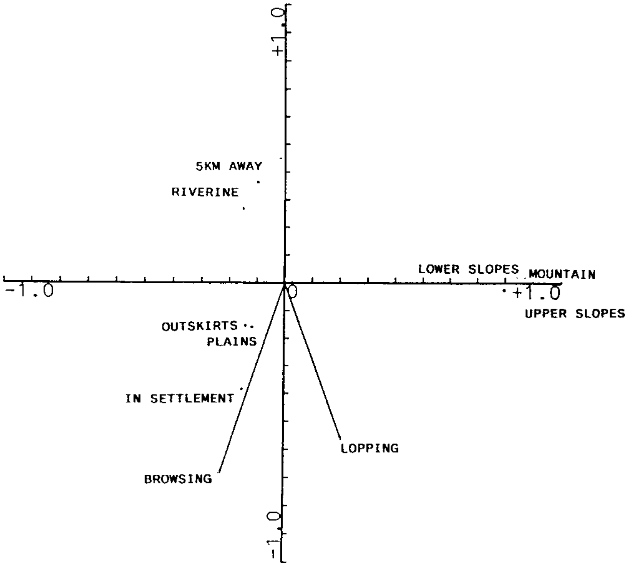

Figure 6c: Environmental variables ordination

Figure 6: CCA ordination diagram of full data set: a. samples; b. species; c. environmental variables.

Key:

Species: FA= *Faidherbia albida*; CW= *Combretum wattii*; PL= *Pechuel-Loeschea leubnitziae*; AE= *Acacia erioloba*; Lsp.= *Lycium* sp.; AT= *Acacia tortilis*; TU= *Tamarix usneoides*; CM= *Colophospermum mopane*; BA= *Boscia albitrunca*; GA= *Gossypium anomalum*; MS= *Maerua schinzii*; BF= *Boscia foetida*; CJ= *Commiphora multijuga*; CL= *Ceraria longipedunculata*; CP= *Commiphora pyracanthoides*; CA= *Catophractes alexandri*; CV= *Commiphora virgata*; CO= *Commiphora* sp. (/aba/hub); CAP= *Combretum apiculatum*; SP= *Salvadora persica*; AS= *Acacia senegal*.

Samples: 1-12= plain; 13-19= riverine; 20-25= mountain.

expected, the effects of browsing and lopping are more intense with increasing proximity to the settlement.

Table 8: Axis 1 and 2 species-environment correlation coefficients from which the CCA ordination diagram is constructed (Figures 6a-c). High values are printed in bold.

Environmental variables	Species axis 1	Species axis 2	Environmental axis 1	Environmental axis 2
browsing	-.2201	-.6272	-.2274	-.6740
lopping	.1970	-.5143	.2036	-.5527
mountain:	.9426	-.0256	.9739	-.0276
lower slopes	**.5047**	-.0054	.5215	-.0058
upper slopes	.7777	-.0295	.8035	-.0317
plains	-.3629	-.4794	-.3750	-.5152
riverine:	-.3093	.5300	-.3195	.5696
in settlement	-.2411	-.5802	-.2491	-.6235
outskirts	-.2858	-.2952	-.2953	-.3173
5km away	-.2252	.7851	-.2327	.8437
% cumulative variance:	18.3%	30%	38.2%	62.4%

In contrast to the mountain samples, the plains and riverine samples, as indicated in Figure 5, were more similar in species composition and thus represented more of a floristic continuum in which distance from the settlement, and the corresponding differences in intensity of human and animal utilisation, were crucially significant. Figures 6a and 6b indicate that both plains and riverine samples located nearer Khowarib shared the greatest similarity in species composition, becoming more divergent in species composition with increased distance from Khowarib and lower intensities of browsing and lopping. This indicates that, in the species composition of these samples, the impact of human and animal utilisation may be overriding the importance of underlying conditions related to topography and substrate.

The overlaying of the species information in Figure 6b onto the sample information in Figure 6a, displays which species are most likely to be found at which samples. Samples 20-25, for example, are characterised by species such as *Terminalia prunioides*, *Acacia senegal* and *Commiphora multijuga*, while samples 16-19 have relatively high proportions of *Combretum wattii* and *Faidherbia albida*. These groups of samples were located in the mountains and in the riverine category 5 km from the settlement respectively.

Analysis 2:

Due to the very distinct nature of the mountain samples displayed by TWINSPAN classification, DCA and CCA, and exemplified by the fact that location in the mountains accounted for the greatest percentage variance in the first CCA, a second CCA was applied to a reduced data set comprised of the more comparable plains and riverine samples. In this case the species-environment correlation for axis 1 was extremely significant (0.919) and this axis explained 17.2% and 54.9 % of variance in the species data and the species-environment data respectively. Reference to the weighted correlation matrix (Table 9) indicates that this is due to the significant effects of browsing (0.7113) and distance from the settlement (-0.8817). These are both measures of settlement impact and indicate that proximity to Khowarib was the most important determinant of floristics in these samples. Lopping, the third measure of human impact, also had a positive effect on species composition (0.5804) but was not as significant as browsing and distance. Axis 2 is determined primarily by location in the plains or riverine areas indicating that these topographic categories would, under conditions of no human and animal disturbance, account for most of the variance in species composition in these samples.

The ordination diagrams in Figs. 7a and 7b provide a clear graphical representation of these relationships. The wide spread of the samples in Fig. 7a, as opposed to clusters around the plains and riverine centroids as seen in Fig. 6a, indicates the comparable nature of these topographic categories in terms of species composition, and the distortion of the data set caused by inclusion of the mountain samples in the first CCA. Fig. 7b, shows very clearly the increasing diversity of species with increasing distance from the settlement, and the tolerance of *Acacia tortilis* under conditions of high levels of human and animal utilisation.

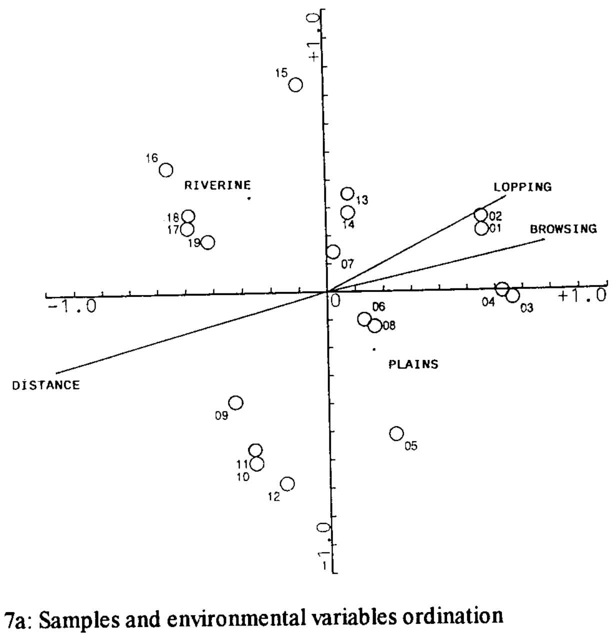

Figure 7a: Samples and environmental variables ordination

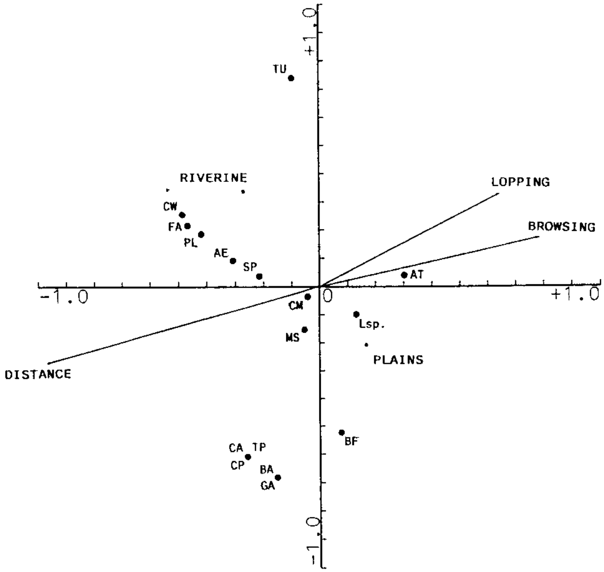

Figure 7: CCA ordination diagrams of the reduced data set (plains and riverine samples only); a. samples and environmental variables; b. species and environmental variables.

Key

Species: FA= *Faidherbia albida*; CW= *Combretum wattii*; PL= *Pechuel-Loeschea leubnitziae*; AE= *Acacia erioloba*; Lsp.= *Lycium* sp.; AT= *Acacia tortilis*; TU= *Tamarix usneoides*; CM= *Colophospermum mopane*; BA= *Boscia albitrunca*; GT= *Gossypium anomalum*; MS= *Maerua schinzii*; BF= *Boscia foetida*; CP= *Commiphora pyracanthoides*; CA= *Catophractes alexandri*; SP= *Salvadora persica*.

Samples: 1-12= plain; 13-19= riverine.

Monte Carlo permutation tests

Unrestricted Monte Carlo permutation tests and partial CCA were applied only to the reduced data set to statistically test the relationship between floristic variation and the surrogate environmental variables chosen to represent human utilization. The forward testing (99 permutations) of the environmental variables using Monte Carlo permutation tests indicated that proximity to the settlement and the associated higher levels of utilization were indeed significant in determining species composition (browsing = p; **distance** = p; **lopping** = p). This significance was maintained for distance and browsing following partialling out of the topographic variables (p and p respectively).

Table 9: Axis 1 and 2 species-environment correlation coefficients for the plains and riverine samples, from which the second CCA ordination diagram is constructed. High values are printed in bold.

Environmental variables	Species axis 1	Species axis 2	Environmental axis 1	Environmental axis 2
browsing	.7113	.1003	.7743	.1703
lopping	.5804	.1899	.6317	.3233
distance	**-.8817**	-.1587	-.9597	-.2703
plains	.5035	**-.4071**	.5481	-.6933
riverine	-.5035	.4071	-.5481	.6933
% cumulative variance:	17.2%		54.9%	

Discussion

Settlement impacts

The above analysis indicates that the Khowarib settlement is having a negative impact on local woody vegetation communities, primarily by reducing species richness and increasing dominance by a handful of tolerant species. This relationship was significant for all three of the environmental variables used as measures of settlement impact, i.e. browsing, lopping, and distance from the settlement. Using similar methods, Shackleton (1993: 247) found a significant loss of woody species richness in a harvested site on communal land in the eastern Transvaal Lowveld, and Vetaas (1993: 170) in northeastern Sudan found a change in physiognomy of vegetation from open woodland to a very open shrubland, which could be at least partly attributed to human and livestock impacts. Within Namibia, Strohbach (1992), again using a similar multivariate approach, also recorded the 'loss of genetic diversity' in grass species, and the increasing density of woody species, with increasing intensities of livestock grazing in the commercial farming District of Grootfontein (northern Kalahari sandveld).

The Khowarib results should be interpreted with a certain degree of caution, however.

First, the data set is comprised of a vegetation survey which only covered an area up to a maximum distance of 5kms away from Khowarib settlement. This calls into question the issue of scale in vegetation analysis generally and, more importantly, it highlights the danger of drawing conclusions regarding human impacts on vegetation from a survey which essentially only confirms the use of woody vegetation resources at a small, local scale. In other words, while humans and livestock may be having what can be described as a negative impact on woody vegetation at a small scale, it would be grossly inaccurate to extrapolate from this that they are having a negative impact on vegetation communities at a large spatial scale. Unfortunately, it is necessary to make this point explicitly because there is a tendency for studies which assert the degradation effects of humans and livestock to not address specifically the temporal or spatial scales over which their results may be applicable.

Second, the conventional view is that the inherently low biomass productivity of perennial woody species in dryland areas makes them relatively vulnerable to utilisation, and pressure on these resources can thus easily exceed rates of productivity, recruitment and replacement. This perception is fueled by a conceptual paradigm which interprets ecological dynamics within a theoretical context dominated by notions of equilibrium, and focusing on both the constancy of driving parameters and processes of change which are gradual and cumulative. In contrast, it may be more accurate to think of woody species as dependent on intermittent and environmentally-driven establishment events which would result in a naturally skewed population structure, and possibly override the significance of the type of small-scale utilisation activities recorded in this study (for a discussion of ecological dynamics in arid systems see, for example, Holling, 1973, 1986; Noy-Meir, 1973; Wiens, 1984; Caughley *et al*, 1987; DeAngelis and Waterhouse, 1987; Ellis and Swift, 1988; Westoby *et al*, 1989; Behnke *et al*, 1993; Homewood, 1993).

Finally, although the incidence of lopping was fairly high in the samples closest to Khowarib it should be stated that very few individuals were cut through the main stem, indicating conservative use and resource management practices by local inhabitants. In addition, many species display mechanisms for surviving high intensities of use. *Colophospermum mopane*, for example, has a remarkable coppicing ability and is thus extremely resilient at an individual and population level, even though it is a species which is sought-after for both building poles and firewood.

Methodological considerations

Given the current focus within Namibia on environmental degradation and possible 'desertification' (cf. Wolters, 1994), particularly in areas characterised by communal land tenure, it is essential that consideration is given to generating information concerning vegetation status and utilisation impacts using sampling and analytical methodologies which are appropriate and replicable. Otherwise, the present situation will continue whereby sweeping statements are made in the absence of evidence concerning the degraded state of vegetation resources due to overuse, largely by communal farmers (cf. van Warmelo, 1962: 39; Loxton *et al*, 1974: 1; Infoscience, 1994: 22).

Although based on a small data set, this study suggests that multivariate statistical techniques may be considered a robust analytical tool for assessing the relative significance of a number of variables, including measures of utilisation, in determining community patterns and composition. In particular, the ability of these techniques to handle complex data sets with a multiplicity of environmental variables, as well as the fact that they do not make sweeping assumptions concerning the way that community data are distributed, enhances their relevance for the assessment of utilisation impacts. Furthermore, the recent use of these techniques by Cowlishaw and Davies (forthcoming) in the Pro-Namib, and their proposed use to analyze vegetation communities in the Kaokoveld (Jürgens, 1995), suggests a growing interest in applying this methodology to the Namibian context.

With regard to the Sesfontein-Khowarib area, a much larger woody vegetation dataset of some 3,000 individuals is currently being collected by Sullivan as part of a longer project defining vegetation resource use by Damara-speaking communal farmers, and assessing the impacts of this use on the vegetation resource base. As an extension of the study presented in this paper, specific issues to be addressed with this new data set include to what extent human and livestock use parameters remain significant in community composition once the spatial scale of analysis has been widened, and the degree by which selection for particular species affects their availability and population structure. This will allow the further interpretation of the Khowarib data set, and will provide additional information for assessment of the methodology described in this paper, as well as highlighting specific resource use issues in the context of assertions made regarding vegetation degradation in this area.

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Appendix 1

Names, families and author citations for plant species mentioned in this paper (following the current species list of the National Botanical Research Institute of Namibia; see also Kolberg *et al*, 1992).

Welwitschiaceae
Welwitschia mirablis Hook. F.

Moraceae
Ficus sycomorus L.

Loranthaceae
Plicosepalus kalachariensis (Schinz) Danser

Portulacaceae
Ceraria longipedunculata Merxm. & Podlech

Capparaceae
Boscia albitrunca (Burch.) Gilg & Benedict
Boscia foetida Schinz subsp. *foetida*
Maerua schinzii Pax

Moringaceae
Moringa ovalifolia Dinter & A.Berger

Fabaceae
Acacia erioloba E.Mey.
Acacia montis-usti Merxm. & A.Schreib.
Acacia robynsiana Merxm. & A.Schreib.
Acacia senegal (L.) Willd. var. *rostrata* Brenan
Acacia tortilis (Forsskal) Hayne subsp. *heteracantha* (Burchell) Brenan
Colophospermum mopane (Kirk ex Benth.) Kirk ex J.Léonard
Faidherbia albida (Delile) A.Chev.
Mundulea sericea (Willd.) A.Chev.

Balanitaceae
Balanites welwitschii (Tiegh.) Exell & Mendonça

Burseraceae
Commiphora giessii J.J.A.van der Walt
Commiphora kraeuseliana Heine
Commiphora multijuga (Hiern) K.Schum.
Commiphora pyracanthoides Engl.
Commiphora virgata Engl.

Euphorbiaceae
Euphorbia virosa Willd.

Rhamnaceae
Ziziphus mucronata Willd. subsp. *mucronata*

Tiliaceae
Grewia bicolor C.Juss.

Malvaceae
Gossypium anomalum Wawra ex Wawra & Peyr. subsp. *anomalum*

Sterculiaceae
Sterculia quinqueloba (Garcke) K.Schum.

Tamaricaceae

Tamarix usneoides E.Mey. ex Bunge

Combretaceae
Combretum apiculatum Sond.
Combretum imberbe Wawra
Combretum wattii Exell
Terminalia prunioides C.Lawson

Apiaceae
Phlyctidocarpa sp. Cannon & Theobald

Salvadoraceae
Salvadora persica L.

Boraginaceae
Cordia sinensis Lam.

Solanaceae
Lycium sp. L.

Bignoniaceae
Catophractes alexandri D.Don

Pedaliaceae
Sesamothamnus guerichii (Engl.) E.A.Bruce

Acanthaceae
Petalidium sp. Nees

Asteraceae
Pechuel-Loeschea leubnitziae (Kuntze) O.Hoffm.

Poaceae
Kaokochloa nigrirostris De Winter