DEGRADATION GRADIENT AS A BASIS FOR MONITORING THE EPHEMERAL OMATAKO FLOODPLAINS OF CENTRAL NAMIBIA

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Abstract

A group of Herero cattle farmers initiated a community grazing trial within a floodplain of the ephemeral Omatako River in central Namibia. A degradation model was constructed from measurements of various characteristics, for determining changes in wetland condition. Species data for Canonical Correspondence Analysis (CANOCO) came from the nearest perennial grass, if present within 5m of the sample point, otherwise from the nearest annual grass. The first ordination axis indicates a degradation gradient, with perennial grass species towards one extreme and annual grasses towards the other. The second axis appears to reflect a moisture gradient, although it was not measured.

INTRODUCTION

Wetlands make up only about four percent of the landscape in Namibia (Hines and Kolberg, 1996). They take several forms, including riverine systems, most of which are ephemeral (Barnard, 1998). Due to Namibia's aridity, the ephemeral rivers form a focus of human settlement which, together with the accompanying livestock, brings about changes in the condition and functioning of the wetlands (Jacobson *et al*., 1995). If such changes are monitored it is more likely that wiser decisions will be made about their management. Flooding may be so rare that such wetlands behave more like rangelands for most of the time. The type of monitoring that is normally applied to rangelands may therefore also be appropriate for such wetlands, with slight modifications.

Stuart-Hill and Hobson (1991) proposed the use of positions of sites in multivariate space, from ordination analysis, to assign condition indices that are devoid of value judgment but which can then be interpreted by different land-users in relation to their objectives. By deliberately selecting sites that cover a wide diversity of degradation states within the same land unit, it is expected that a degradation gradient will occur in the first ordination axis (Bosch and Kellner, 1991), ordering the sites from best to worst condition. Grass species composition, as determined by point sampling that records the nearest plant (Everson *et al*., 1990), has formed the basis of many rangeland condition assessments techniques (Hurt and Bosch, 1991), including those using ordinations (e.g. Bosch & Kellner 1991). The use of species composition alone is not ideal because

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it is a proportional measure and not an absolute measure (Kirkman, 2002). One way to partly overcome this problem is to combine perennial grass species composition with an index of perennial grass density, through the use of a surrogate species of "no perennial" for points that have no perennial grass within a given distance from the point (Zimmermann *et al*., 2001a). This combination, by converting an index of perennial grasss density to a surrogate species, still allows ordinations of the type that are applied to species data alone, such as Detrended Correspondence Analysis (DCA) and Principal Components Analysis (PCA) (e.g. Bosch and Gauch, 1991). An alternative way to partly overcome the problem of species data being a proportional measure, may be to incorporate additional variables into ordination space, through combining habitat data with species data, as can be done in ordinations such as Canonical Correspondence Analysis (CCA) (Jongman *et al*., 1995).

STUDY AREA

At the village of Omatupa, in communal land of central Namibia, the farmers' association has applied a grazing trial by fencing off certain portions of the land and allocating different treatments. The total area of 25ha is divided into three different management zones. One consists of four paddocks of 1.5ha each, used for rotational grazing by a single cow. The second is an exclosure of 3.5ha, from which livestock will be excluded at all times. The third is a paddock of about 15ha where a fairly large herd of cattle will be kept for short periods, followed by long recovery periods. This trial, designed and run by the community, provides a good opportunity for obtaining quantified information on the rangeland condition as influenced by the treatments, in collaboration with the farmers. Ideally some "before" measurements should have been taken, to provide a point of reference, but the facilitator did not want further outside intervention in the initial phases of this community work, until the farmers felt full ownership of their trial. The grazing trial site had been fenced since the start of the rainy season, and the survey was conducted at the end of the season. However it was only fenced with strands of wire that prevented cattle from entering, while sheep and goats could still get through. No cattle had yet been put in, to provide the required treatments.

In order to allow meaningful interpretation, the trial sites need to be compared with other sites where edaphic and macro-climatic conditions are similar but management differs. The grazing trial site falls within the floodplain of the ephemeral Omatako River. Surveys were therefore undertaken at six sites in and around the grazing trial, and at 18 sites within floodplains of different grazing histories. The furthest distance between sites is about 60 km. A map that shows their distribution appears in Figure 1. The six most western sites fall within a major tributary, while all the others occur along the main Omatako channel. A brief description of each site appears in Table 1.

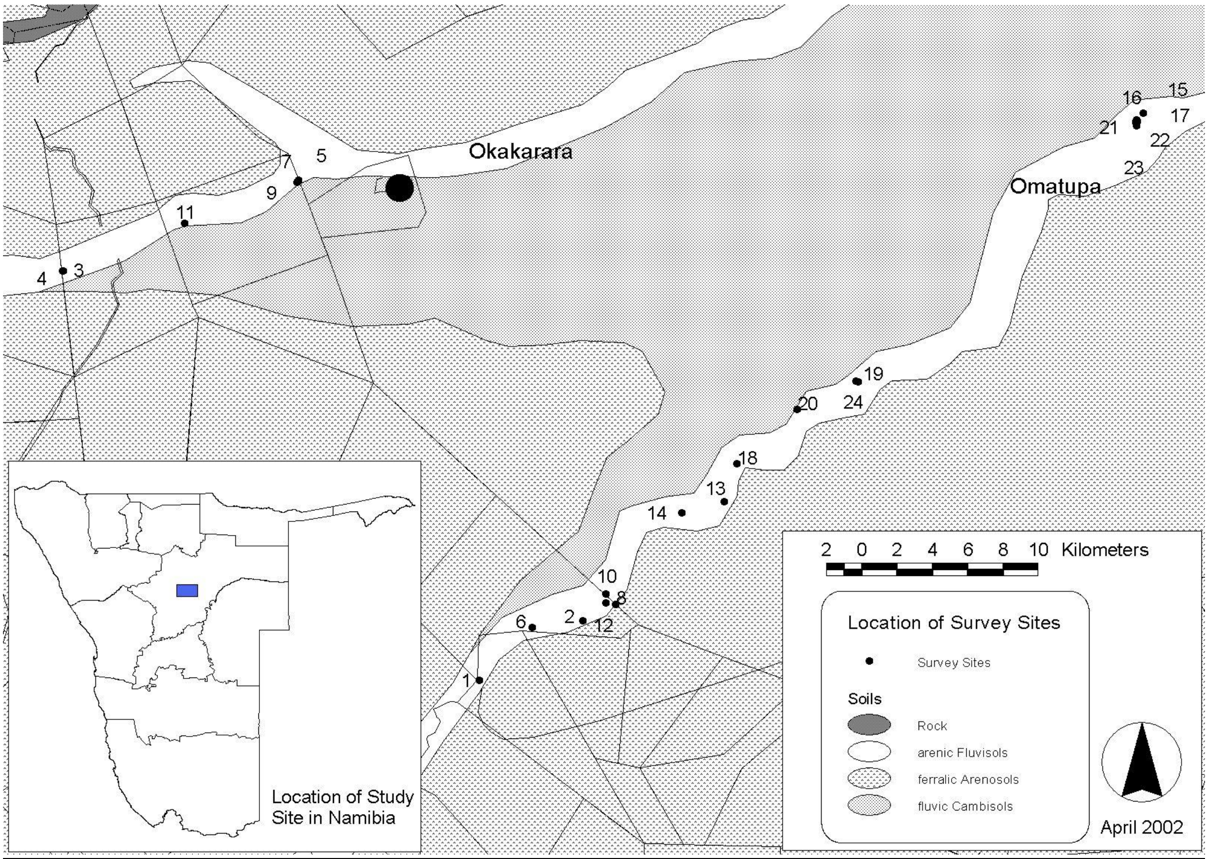

Figure 1. *Location of the survey sites where measurements of wetland condition were taken. The survey site numbers correspond with those in Table 1. The straight lines on the west and south represent boundaries of commercial farms, while communal land occupies the central and eastern part of the map. The rock in the northwest is part of the Waterberg mountain range.*

Sites were selected on the basis of covering a wide diversity of conditions, while still being representative of the fairly narrow floodplains where *Acacia tortilis* was the dominant woody species. The different types of management being applied ranged from communal grazing by mixed domestic livestock, commercial grazing by cattle or game animals and some areas cleared of bushes. A brief description of each site appears in Table 1.

Table 1. *The 24 survey sites in the Omatako floodplains, listed in order of condition score, which was determined from position of sites along the first ordination axis of the Canonical Correspondence Analysis, as explained in the text.*

No.	Location of site	Brief description of management	Score
1	Vaalwater	Cattle stocked at ±15 kg/ha: 8 paddocks per herd (p/h)	100
2	Aroma mid	Cattle stocked at ±40 kg/ha: 4 pd/h, plus occasional sheep	92
3	Klein Hamakari	Cattle stocked at ±20 kg/ha: 5 paddocks per herd	78
4	Omujomatemba	Cattle stocked at ±30 kg/ha: 6 paddocks per herd	77
5	Okakarara	Continuous heavy grazing, roughly 5 km from village	76
6	Aroma near	Cattle stocked at ±40 kg/ha: 4 p/h, plus frequent sheep	74
7	Hamakari far	Game ±45 kg liveweight/ha, woody plants cleared for security strip	74
8	Uahupirapi near	Continuous moderate grazing, roughly 1 km from water point	73
9	Hamakari mid	Game ±45 kg liveweight/ha, bushes not cleared	73
10	Uahupirapi far	Continuous moderate grazing, roughly 3 km from water point	73
11	Hamakari near	Game ±45 kg liveweight/ha, bushes often cleared but trees remain	72
12	Aroma far	Cattle stocked at 40 kg/ha: 4 paddocks per herd, too far for sheep	70
13	Okahitua mid	Continuous moderate grazing, roughly 4 km from village	69
14	Okahitua far	Continuous moderate grazing, roughly 6 km from village	67
15	Omatupa omuramba	Continuous heavy grazing, in vicinity of village	64
16	Omatupa exclosure	Previously continuous grazing, now fenced for trial, to be exclosure	50
17	Omatupa north	Continuous heavy grazing, in vicinity of village	45
18	Okahitua near	Continuous heavy grazing, roughly 2 km from village	42
19	Orunahi near	Continuous heavy grazing, in vicinity of village	30
20	Orunahi fence	Continuous heavy grazing, in fenced area serving six villages	24
21	Omatupa free choice	Previously continuous grazing, now fenced for trial, to be managed	15
22	Omatupa trial rotate	Previously continuous grazing, now fenced for trial, to be rotated	5
23	Omatupa south	Continuous heavy grazing, in vicinity of village	4
24	Orunahi far	Continuous heavy grazing, roughly 3 km from village	0

All study sites fall within the agro-ecological zone described by De Pauw *et al.* (1999) as Central Plateau, Southern Omatako Plain. Its landform type is alluvial plain, with a weakly oriented drainage pattern and a regional slope range of 0-2%. The soils at the study sites all fall within the fairly narrow drainage lines of arenic Fluvisols, which are mostly surrounded by fluvic Calcisols on one side and ferralic Arenosols on the other. The mean annual rainfall is about 400 mm, although at the time of the surveys, towards the end of the 2002 rainy season, most sites had received less than 200 mm. The natural flows of water down the Omatako River have been greatly interfered with by upstream dams, many on farms, but most significantly by the Omatako Dam of 43.5 Mm^3 capacity (Christelis and Struckmeier, 2001) that the State built in 1984 (Stern and Lau, 1990).

OBJECTIVES

The objectives of the study were to:

- Provide baseline data for monitoring of the community grazing trial.
- Provide a benchmark to show the potential of the wetlands and differentiate between the influences of climate and management.
- Construct a degradation model from which changes in wetland condition could subsequently be determined.
- Gain some understanding of how the diverse soil conditions influence vegetation composition.

PROCEDURE

Field work

Surveys were undertaken in April 2002. The alignment of transects was determined subjectively while walking along the floodplain, starting on one side of the main water channel and meandering with the channel, usually half way between the channel and the start of domination by dryland woody species, such as *Boscia albitrunca* and *Acacia mellifera*. Measurements were taken at 200 points per survey site, which had been found by Zimmermann *et al*. (2001b) to be adequate for most of the measured variables. The points were spaced roughly 10m apart along the transects, through a combination of uniform pacing and randomly thrown dart. The observer paced about 8m and then turned 180^0 and threw a dart roughly 2m over the shoulders in the direction of the transect. There were some atypical patches encountered along the transects, such as termitaria and micro-depressions filled with mono-stands of the grass *Eragrostis rotifer*. Such patches were subjectively avoided, either by walking around, or by extending the position, from which to throw the next dart, to the just beyond the patch, in the direction of the transect. Usually 100 points were measured along a transect on one side of the channel, after which the channel was crossed and another 100 points measured on the return route on the opposite floodplain. At each survey site a soil sample was taken from the top 10 cm. In addition a panorama of three fixed-point photos was taken at the start of the transect, facing southwards with a person standing 10m away, until the camera failed to function after the 13th survey. The intention had been to establish photographic records for each site, from which changes in relative abundance of categories of plants could be quantified by ranking in comparison with previous photos, as described by Zimmermann *et al.* (2001b).

At each point along the transects, where the dart landed, the following were recorded:

- Distance to the nearest live perennial grass, provided that it was at least a year old, as evidenced by grey material, unless there was no such grass within 5m of the point.
- Species of the nearest live perennial grass, unless there was no such grass within 5m of the point, in which case the species of the nearest annual grass.
- Number and species of woody plants shorter than 0.5m within 0.75m of the point.
- Distance to the nearest woody plant taller than 0.5m, unless it was further than 5m from the point.
- Species of the nearest woody plant taller than 0.5m, if within 5m of the point.
- Height class of the nearest woody plant taller than 0.5m, whether 0.5-1m, 1-2m, 2-3m or >3m.
- Whether the dart landed on bare soil, mulch or the base of a live perennial grass.
- Species of woody plant, if the plant was taller than 0.5 m and if the point fell under its canopy.
- Height at which a disc pasture meter settled on the herbaceous layer.
- Latitude and longitude coordinates of the position from which the dart was thrown, as read from a Global Positioning System (GPS).

To calibrate the disc pasture meter, at four points per site (point numbers 25, 75, 125 and 175) a 2m x 2m quadrat was laid out and nine disc pasture meter readings taken before all the grass was clipped and weighed fresh on site with a grab sample taken to determine moisture content (Trollope and Potgieter, 1986). Each soil sample was divided into two portions. One portion was sent for the standard farm soil analysis at the Ministry of Agriculture's laboratory. The other portion was further subdivided into 8-10 pots and sown with seeds of radish (*Raphanus sativus*) for bioassay (Ward *et al*., 2000). This was done to obtain an index of overall soil fertility, from the resulting mean fresh weight of radishes obtained, although root diameter and length of the longest leaf were also measured.

It was not possible measure woody canopy cover with a Bitterlich gauge (Friedel and Chewings, 1988) because the width of the transect so sampled would have been too great and included parts of the surrounding dryland. Instead the point sampling was used for this. The inclusion of distance measurements from points to nearest plants allows not only the determination of a density index, but also the characterization of bare patch size frequencies (Freidel *et al*., 2000).

Data analysis

Raw data was fed into an Excel spreadsheet (Microsoft 2000) and pivot tables were used to obtain overall estimates of the different variables per site. Various combinations were used for obtaining the species data. Some species were lumped together to avoid identification problems for those species occupying similar niches. The species and their abbreviations are shown in Table 2, together with their maximum occurrence at any site, whether they are annual or perennial, and whether they are more common in damp places or along water courses, as indicated by Müller (1984) or Gibbs Russel *et al*. (1991), with nomenclature following the latter.

When determining the perennial grass species composition a surrogate species, called "no perennial", was allocated if there was no perennial grass within various cut-off distances from the dart point. Combinations included those with cut off distances at 0.3m, 1m and 5m from the dart point. Another combination was derived from both annual and perennial grass species, whereby the nearest perennial grass was used, if present within 5m, and if absent then the nearest annual grass species was used instead. Further combinations incorporated woody species into the composition to derive species data, if the pointed landed below a woody canopy, while the proportion of woody plants taller than 3m was also tried in another combination.

Table 2. *The 30 grass species, or groups, differentiated during the surveys in the Omatako floodplains, together with their abbreviations used in Figure 3, their maximum occurrence at any of the 24 sites, whether annual or perennial and whether they are more commonly found in drylands or wetlands.*

Species or Group of species	Abbreviation	Max. %	Life form	Usual habitat
Aristida adscensionis	AADS	4.5	Annual	Dryland
A. congesta	ACON	21.5	Perennial	Dryland
A. effusa	AEFF	0.5	Annual	Dryland
A. meridionalis	AMER	2.0	Perennial	Wetland
A. stipitata subsp. stipitata	ASTI	15.5	Perennial	Dryland
A. stipoides	ASTS	3.5	Annual	Dryland
Bothriochloa radicans	BRAD	12.0	Perennial	Wetland
Cenchrus ciliaris	CCIL	4.5	Perennial	Dryland
Chloris virgata	CVIR	24.5	Annual	Wetland
Cynodon dactylon	CDAC	20.5	Perennial	Wetland
Dactyloctenium aegyptium	DAEG	0.5	Annual	Wetland
Echniochloa holubii	EHOL	0.5	Perennial	Wetland
Enneapogon cenchroides	ECEN	1.0	Annual	Dryland
Eragrostis biflora	EBIF	0.5	Annual	Dryland
E. cylindriflora and E. porosa	ECYL	95.5	Annual	Dryland
E. echinochloidea	EECH	1.0	Perennial	Wetland
E. omahekensis	EOMA	4.5	Annual	Dryland
E. rigidior	ERIG	5.5	Perennial	Dryland
E. rotifer	EROT	34.0	Perennial	Wetland
E. tricophora and E. lehmanniana	ETRI	98.0	Perennial	Dryland
Melinis repens subsp. repens	MREP	0.5	Annual	Dryland
Panicum coloratum and P.lanipes	PCOL	84.5	Perennial	Wetland
Pogonarthria fleckii	PFLE	1.5	Annual	Dryland
Schmidtia pappophoroides	SPAP	2.5	Perennial	Dryland
Sporobolus fimbriatus	SFIM	0.5	Perennial	Wetland
Stipagrostis uniplumis	SUNI	69.5	Perennial	Dryland
Tragus berteronianus	TBER	7.5	Annual	Dryland
Tragus racemosus	TRAC	1.0	Annual	Dryland
Urochloa brachyura	UBRA	1.5	Annual	Dryland
U. oligotricha	UOLI	29.0	Perennial	Wetland

The habitat data are shown in Table 3, which also indicates how they were obtained. Explanations for those that could not fit into Table 3 are as follows:

Distance measurements were converted to an index of density, as follows:

$$\text{Density index, in plants/ha} = \frac{100\ 000\ 000}{2\vartheta \times d^2} \qquad (1)$$

where ϑ = Pi, and d = the median distance in cm from the nearest plant to the point. This formula was adapted from that given by Mueller-Dombois and Ellenberg (1974:107). Median distance was used instead of mean, because the distribution of distances is skewed. The adaptation assumed that the median distance represents the radius which, when converted to area, represents half of the area available per plant, since there is an equal probability of the dart landing within this radius of its nearest plant and landing beyond this radius.

There were seven sites for which a median distance to the nearest perennial grass could not be obtained, because more than half of their points had no perennial grass within 5m of the point. To overcome this problem for these sites the median distance of those points that did have the nearest perennial grass within 5m was used in Formula (1) and the density estimate so obtained was corrected for by Formula (2) below, which assumes that the density was zero for the 5m radius plots sampled where there was no perennial grass within the 5m.

$$\text{Density index in plants/ha} = \text{Answer from Formula A} \times \frac{(100 - b)}{100} \qquad (2)$$

where b = the percentage of bare points, with no perennial grass within 5m.

The measure of density obtained by these formulae is still only an index, because it does not account for the degree of clumping amongst the plants (McNeill *et al*., 1997), and therefore underestimates the true density. It could, however, be useful for comparative purposes, especially between sites that have roughly the same degree of clumping.

The combinations of species and habitat data were imported into the CANOCO 4 program (Ter Braak and Smilauer, 1998) and analysed. The combinations of species data were first ordinated by DCA, to gain a feeling for the pattern that emerged from the species data alone and whether the sites were ordered roughly according to their state of degradation, as described by Bosch and Gauch (1991). Then the species combinations together with the habitat data were subjected to CCA. The combinations that resulted in first axis eigen values below 0.5 were discarded. The remainder was subjectively inspected and the combination that appeared to give the clearest interpretation was retained. Up to three possible outliers were removed, one at a time, to determine the influence of their removal on the new patterns that emerged from the remaining points. The relative position of each site along the first ordination axis was used to calculate a wetland condition score, through proportional transformation to a scale where 100 represents the score of the best site and 0 the worst site.

Table 3. *The 12 habitat variables, differentiated during the surveys in the Omatako floodplains, together with their abbreviations used in Figure 3, an indication of how they were determined and the range of values that was found between sites.*

Habitat indicator	Abbrev.	How determined	Range between sites
Bare ground for perennial grasses	BG	% of points with no live perennial grass of at least a year old within 1m	3.5-97.5%
Bare ground for woody plants, taller than 0.5m	BW	% of points with no woody plant, taller than 0.5m, within 5m	0.0-97.5%
Clay content of the soil	Cl	Dispersion and pipette method, to get %	2.8-35.5%
Density index for big woody plants, taller than 0.5m	DB	From distance measurements, as explained in text	93-1592 plants/ha
Density index for perennial grasses	DG	From distance measurements, as explained in text	122-55098 plants/ha
Density of short woody plants, below 0.5m	DS	Counts within circular plots of 0.75m radius around points	85-2094 plants/ha
Nutrient status of the soil	Nt	Mean fresh weight of radishes grown in soil	4.2-19.2 g/radish
Organic matter content of soil	OM	% weight loss through ignition at 360^0C for 4 hours	0.26-1.52% of dry mass
PH of the soil	pH	1 soil : 2.5 water ratio suspension on a mass to volume basis	6.09-7.37
Woody canopy	WC	% of points covered by canopies of woody plants taller than 0.5m	2-60%
Yield of aboveground grass dry matter	YG	Through calibration of settling height of disc meter (r^2=0.79)	223-2375 kg/ha
Percentage of exposed soil	%S	% of points with no mulch or basal cover	67.5-99.5%

RESULTS AND DISCUSSION

The ordination that made use of a combination of annual and perennial grass species gave a better interpretation than the combinations making use of perennial grasses alone plus a surrogate species of "no perennial" at different cut-off distances. This differs from the findings of Zimmermann *et al*. (2001a), where the inclusion of a surrogate species using a 0.3m cut-off distance gave a fairly good indication of rangeland condition in Namibia's Camelthorn savanna. Perhaps the differentiation between the different species of annual grasses is more important in the Omatako floodplains, because the most abundant annual grass, *Eragrostis cylindriflora*, is of poor quality while *Chloris virgata*, which was common at some sites, is a valuable grazing grass (Van Outshoorn, 1999:231).

The combination of annual and perennial grasses also gave a better ordination interpretation than the combinations that included woody species. The fact that some sites had been purposefully cleared of bushes, and that some other sites were subjected to different levels of wood harvesting, may have contributed to the lack of significant influence of woody species in ordering the sites along the ordination axes. In addition, the taller woody plants that have escaped harvesting may be a better reflection of conditions that occurred centuries ago, while grasses have respond faster to more recent grazing impacts.

The ordination that made use of a combination of annual and perennial grass species was therefore retained as the most appropriate for further interpretation. It gives an eigen value of 0.63 for the first axis and 0.46 for the second. Its DCA ordination corresponds fairly closely to that from CCA, with the first axis scores from each method correlating well with each other (r^2=0.95), suggesting that the species data has a greater influence on the first ordination axis than the habitat data. Removal of the apparent outliers did not significantly improve the eigen values, so they were left in.

The first axis of the CCA ordination appears to indicate a degradation gradient, because the perennial grass species are mostly at one extreme and annual grasses at the other, as can be seen in Figure 2. The sites ordination is shown in Figure 3, in the biplot with habitat data. Out of the 12 habitat variables tested, the one called "bare ground", which was represented by the percentage of points with no perennial grass within a one meter cut-off distance, gave the best correlation with wetland condition (r^2 = 0.76). The density index of woody plants taller than 0.5m correlated best with the second ordination axis (r^2 = 0.49). However a further look at this correlation showed that two extreme sites, 1 and 2, contributed disproportionately to it. Without these two sites the correlation gives $r^2 = 0.001$. Furthermore, a look at the grass species ordination in Figure 2 suggests that the second axis is more a reflection of moisture gradient, with dryland grass species, such as *Stipagrostis uniplumis*

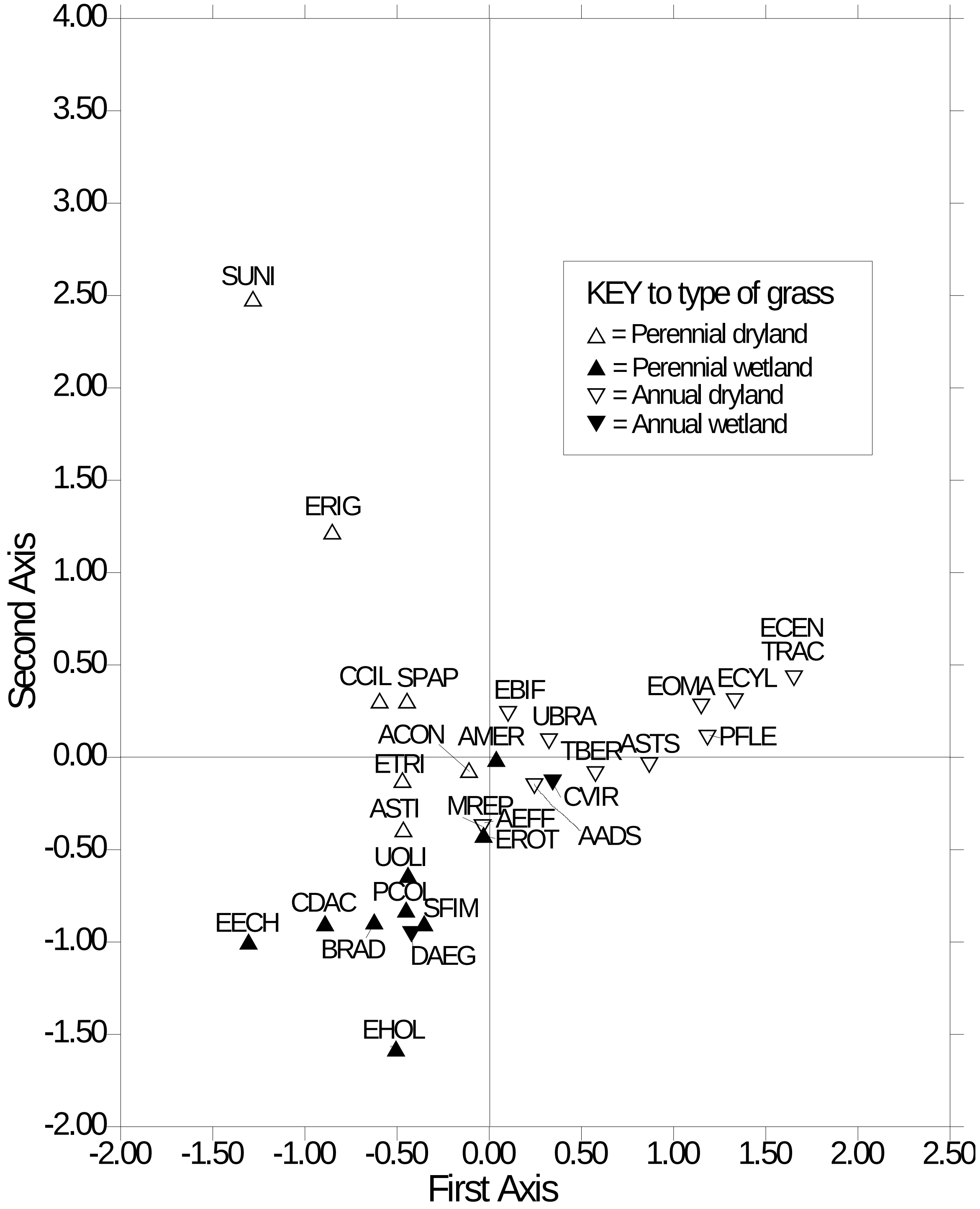

Figure 2. *Ordination diagram (Canonical Correspondence Analysis) of grass species data, obtained from surveys in the Omatako floodplains. Short lines point to the triangles that represent species for which the name could not fit in above the triangle. The abbreviations for the species correspond with those in Table 2.*

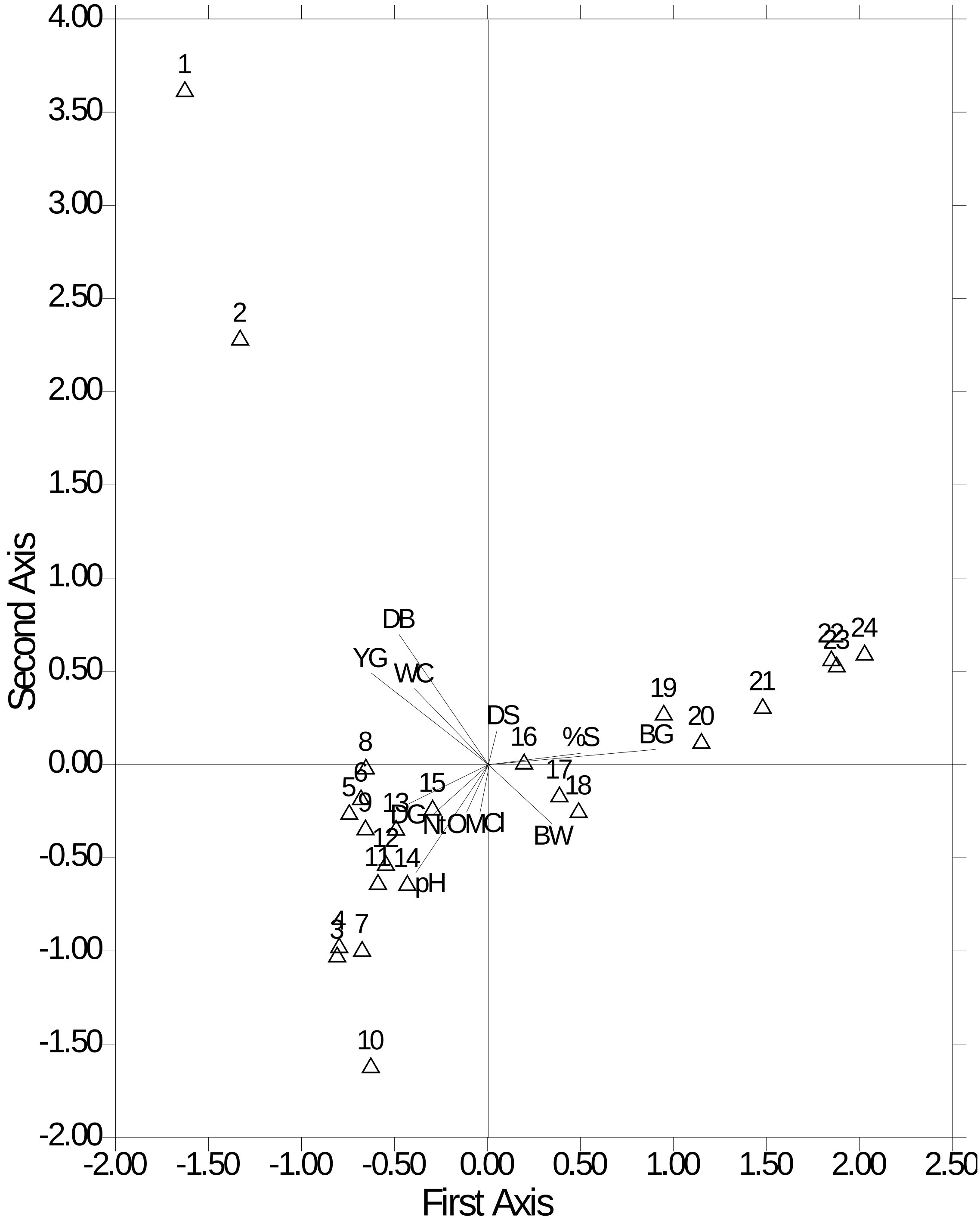

Figure 3. *Ordination biplot (Canonical Correspondence Analysis) of the 24 sites, surveyed in the Omatako floodplains, and the 12 habitat variables. The sites are represented by triangles, for which the numbers correspond with those in Table 1. The habitat variables, for which the abbreviations correspond with those in Table 3, are represented by lines emanating from the centroid. The direction of the line shows the way that the variable increases in relation to the two axes, while its length indicates how well it relates to the two axes.*

and *Eragrostis rigidior*, dominating the upper end of the axis, while wetland species, such as *Echinochloa holubii* and *Panicum coloratum* dominate the lower end of the axis. Unexpectedly clay content did not correlate well with the second axis ($r^2 = 0.07$) so cannot be used to indicate the moisture gradient. Due to the flooding characteristics and changing channels, higher clay contents are not necessarily related to higher humidity, in fact most central portions of channels are very sandy (Verlinden, *pers. comm*.).

Sites 1 and 2, which were allocated the best condition scores, are those on the driest side of the moisture gradient. Therefore they might not serve as a good comparison for the others. They were probably sampled too high up the floodplain in comparison with the other sites. It may, nevertheless, be useful to keep them in the degradation model, so that the degree of "dryness" of any new site can be tested by feeding its scores into the model.

The six sites along the tributary were all scored close to each other, ranging from 73-78, even though there were some notable differences, which will be illustrated by comparing Sites 5 and 7 (see Table 4). Site 5 is on communal land that is continuously grazed at a high stocking rate, while Site 7 is just across the fence in a commercial game farm. Cattle had been rotationally grazed until a year previously on the game farm at a light stocking rate of about 20 kg liveweight ha^{-1}, but its game animals now come to about 45 kg liveweight ha^{-1}. The larger woody plants were manually cleared from Site 7 two years previously, while a follow-up herbicide treatment was applied to small and re-growing bushes shortly after the measurements were made. Site 7 is also compared in Table 4 with Site 9 on the same game farm, the only difference in management is that woody plants were not cleared at Site 9, which is more typical of the majority of the game farm, while Site 7 is a cleared strip of only about 100m width along the fence.

It is interesting that Site 5 received a relatively high score of 76, despite being on communal land. Out of all 24 sites it had the highest density index of 55 099 perennial grasses/ha, while at Site 7 the density index was 6 499 perennial grasses/ha. Yet the communal site had a fairly low grass yield of 615 kgDM ha^{-1}, compared with 1 390 kgDM ha^{-1} just across the fence in the commercial farm. This shows how heavily utilised the communal site is. Its dominant perennial grass species were *Eragrostis tricophora* and *E. lehmanniana*, making up 98%, compared with 46.5% just across the fence on the commercial farm. These species are generally considered to be of intermediate quality for grazing. Although the commercial site had a lot of *Panicum coloratum* and *P. lanipes*, generally considered to be of excellent quality, and making up 44.5% of the species data, these better grasses were at low density. The communal site also had the second highest density of small woody plants of 1 726/ha. The trampling during heavy use might improve conditions for germination of seeds, which can then establish themselves during subsequent rest. It is, however, unknown how the stocking rate fluctuates seasonally at this site, but the dominant *Eragrostis* species probably do not need that much rest to establish themselves, as they are considered to be pioneer or subclimax species. The majority might even have established themselves during a recent good rainy season, such as 1999/2000 when there was a great abundance of grass, and they might currently be on their way out again. It is also interesting that Site 5 appears to be on the drier side of the second axis moisture gradient, while presumably experiencing the same flooding and rain as Site 7. Perhaps this is a reflection of the effectiveness of the water cycle, with Site 5 presumably experiencing more runoff and evaporation, as its mulch and grass basal cover is only 8.5%, compared with 21.5% at Site 7. If the differences between Sites 7 and 9 were caused by the clearing of woody plants, then it seems that the clearing resulted in a lower perennial grass density, while only reducing the phytomass slightly. This implies that the average size of a grass plant was greater in the cleared strip. It is unclear whether this is because of the greater grazing pressure by wild animals in the uncleared area, due to perceived danger of grazing in the cleared area in view of passers-by along the fence, or because of the smaller grasses dying out first in the cleared strip, while some larger grasses such as *P. coloratum* apparently increased.

Table 4. *Comparison between three nearby sites, one on communal land and two on a game farm, one of which is regularly cleared of woody plants, the other of which is uncleared, while the third is on communal land on the other side of a cordon fence.*

Characteristic	Site 5 (Communal)	Site 7 (Game farm, woody plants cleared)	Site 9 (Game farm, uncleared)
Condition score, from 1st ordination axis	76	74	73
Dryness score, from 2nd ordination axis	26	12	24
Perennial grass density index (plants/ha)	55 099	6 499	17 604
Bare patches for grass (% of points with no perennial grass within 1m)	3.5	17.0	12.0
Dry matter yield (kg/ha)	615	1 390	1 214
Density of woody plants shorter than 0.5m (plants/ha)	1 726	226	311
% canopy cover by woody plants taller than 0.5m	18.5	2.0	21.0
% of soil covered by mulch or bases of perennial grass	8.5	21.5	13.0
% of *Panicum coloratum* (excellent perennial grass)	0.5	44.5	4.5
% of *Eragrostis tricophora* (poor quality perennial grass)	98.0	46.5	80.5
% of *Aristida congesta* (poor quality perennial grass)	1.5	0.0	10.0
% of *Eragrostis rotifer* (perennial grass that indicates periodic water logging)	0.0	9.0	4.5

CONCLUSIONS

The first ordination axis appears to represent a degradation gradient, as evidenced by both the relative occurrence of annual and perennial species and the correlation with the percentage of points with no perennial grass within 1m.

The second ordination axis might represent a moisture gradient, as evidenced by the occurrence of wetland and dryland species. However an adequate indicator of moisture regime was not included in the measurements. One possible way to measure it could be by wading to each tenth sample point as soon as a recent flood has stopped flowing, and measuring the depth of standing water.

Monitoring the vegetation of wetlands by rangeland management methods is more difficult than applying them to drylands that are more homogenous, because the alignment of the transect is so crucial to the outcome of the former. A slight upslope movement is likely to result in a greater contribution of dryland species, while a slight downslope movement is likely to result in greater contribution of wetland species. This is further complicated by the undulating micro-topography, which results in some points higher in the floodplain retaining water for longer than some lower points, because of occurring in micro-depressions. The width of the floodplain may also have an influence. Where it is narrow and sloping it is likely that dryland species encroach more easily onto it during long periods without significant floods, than where the floodplain is wide and flat.

The moisture gradient makes it unlikely that the degradation model can be validly extended to other sites not represented on the current degradation gradient, even within the same ephemeral river system. It questions the validity of comparing the wetland condition of new sites with those already measured. However, the fact that points had their GPS coordinates recorded means that the same points can easily be re-located in the future. This can allow tracking of changes in ordination space, to monitor the changes in wetland condition at those particular sites over time.

The use of the first ordination axis in allocating a single condition score may be convenient, but not always sufficient, as illustrated by the comparison between Sites 5 and 7. They were allocated almost the same condition score, but one had a high density of poor perennial grasses while the other had a low density of good grasses. Of course it is up to land managers to decide which of the two conditions they would prefer, taking into account not only the wetland condition and its ecological support services, but also the products obtained from the land and the livelihoods supported by it. Examination of ordination space might show differences in where sites, with similar condition scores, lie along the moisture gradient. If this is due to difference in effectiveness of the water cycle, and not due to difference in sample positions within the floodplain, then it could help to distinguish between the health of such sites.

It is hoped that the 15ha managed grazing area in the Omatupa trial site will eventually serve as a benchmark for comparison with the surrounding floodplains. However, it might take many years for its condition to improve sufficiently. Therefore some of the surveyed sites in better condition could act as temporary benchmarks in the meantime. Sites 1 and 2 would not be sufficiently representative due to their dryland bias, so the best temporary benchmarks could be Sites 3 and 4, although further away. The benchmarks will show farmers the potential of the floodplains, if better managed.

ACKNOWLEDGEMENTS

Gero Diekmann and Reinhardt Kapuihe are gratefully acknowledged for facilitating the community grazing trial and inviting the Polytechnic of Namibia to participate in the monitoring. Tiree Kahuure of Omatupa took an active interest in the monitoring and provided valuable assistance. Filippus Tjitere kindly informed the communities that the monitoring would take place in their areas. Farmers F. Diekmann, W. Diekmann, Dörgeloh, Hassenpflug, Herbst, Uahupirapi and the many communal farmers are thanked for allowing the monitoring to take place on their land. Assistance with fieldwork was kindly provided by Polytechnic of Namibia staff members Patrick Graz and Nyambe Mwazi, Directorate of Foretstry's Rabanus Shoopala, and by Polytechnic students Timoteus Amadhila, Antonio Andrade, Thomas Gawaseb, Gertruida Haingura, Eliaser Hamutenya, Fillemon Iifo, Megameno Kambonde, Ishmael Kapuka, Seselia Kauma, Silvester Kavara, Paul Negongo, Maria Negumbo, Daniel Shapi, Matthews Shiningeni, Patrick Tibinyane and Macdonald Tjiuitju. Thanks also go to Gerd Wölbling for providing a convenient camping site for the eight days of the fieldwork. Patrick Graz is furthermore thanked for production of the map. The assistance of Alex Verlinden with use and interpretation of CANOCO is also much appreciated, as well as his comments on the draft. Finally, but not least, the Universities of Botswana and Florida are thanked for organizing the conference at which this work was presented.

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