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THE POTENTIAL VEGETATION OF THE UPPER ORANGE RIVER, SOUTH AFRICA: CONCENTRATION ANALYSIS AND ITS APPLICATION TO RANGELAND ASSESSMENT

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Abstract. The potential vegetation of the upper Orange river, South Africa, was modelled using floristic data from 377 Braun-Blanquet quadrats collected by M.J.A. Werger from 1971-1973. The median annual rainfall (MAR) and altitude (ALT) for each quadrat were extracted from a surface response model of MAR for southern Africa and a digital terrain map. MAR and ALT were divided into classes at 25 mm and 100 m intervals respectively. A cross tabulation was prepared for each community, providing frequencies for each cell. A contingency table of the frequencies provided a model for each community. Where the null hypothesis of independence was reejected, the cells with the highest frequencies were selected as the optimum conditions for each community.

Using all data from the model of MAR and ALT, all minute by minute co-ordinates between 30°S 24°E and 31°S 28°E which satisfied those conditions were classified into eight plant communities. Thirteen thousand four hundred and forty km^2 or 4966 pixels (33.6%) were classified. These communities were plotted as a digital map representing the potential vegetation.

The validity of the hypothesis was tested by comparing the digital map with Acocks' (1988) map of the study area. A relationship between the model and the Acocks map, which was prepared after an intensive survey and photo-interpretation in 1950, is discernable. The digital map follows the course of the Orange river, including its tributaries the Caledon and Seekoei rivers. This is attributable to the geographical limits of the Werger study. The communities extend from the grasslands in the east, through the grassy shrublands (Grewio-Rhoetalia and Stachyo-Rhoetum) to the Pentzietea incanae and Stipagrostion in the west. The communities follow an east-west aridity gradient, with the median annual rainfall of samples ranging from 663 mm to 229 mm.

Introduction

Within the community-unit concept (Shipley and Keddy 1987), the plant community is the basic unit, representing a group of relatively homogeneous samples. The samples, when classified into a hierarchical table, provide associated environmental variables which may be directly related to the distribution of the communities. The results of a hierarchical classification of samples using the methods of the Zürich-Montpellier school of phytosociology provides the units comprising each plant community.

In the semi-arid Karoo region of the southern Africa, precipitation appears to be the most important vegetation determinant, with small changes (25-50 mm per annum) influencing the shift from grassland to dwarf shrubland (Palmer 1988). The relationship between plant communities, classified using the community unit concept, and precipitation, has traditionally been difficult to model. Inadequate rainfall data are the main reason for this. Precipitation data were generally not available for each sample comprising a community, as the sample sites are situated far away from rainfall recording stations. Vegetation ecologists have generally limited interpretation of the relationship between the environmental variables and a community to those more easily measurable variables such as altitude, geology, soil-type, rockiness, terrain form and management treatment. The recent development of interpolated rainfall models (Dent *et al.* 1989) and the associated digital elevation models, provide the basis for associating total floristic samples with these variables.

Rainfall is a direct environmental gradient (Austin 1980) which has a presumed effect on plants but is not readily measurable. Median annual rainfall (MAR), a better measurement of rainfall than the more conventional mean (Erasmus 1987, Hill and Morgan 1981), provides an index of aridity in semi-arid areas, and has been used successfully in direct gradient analysis (Austin and Cunningham 1981).

Altitude is an indirect environmental factor, which influences plant growth through correlated changes, and can be partitioned into several direct environmental factors (temperature and rainfall). These variables change in a complex fashion with latitude and longitude. Altitude is a surrogate for a complex set of factors, and is location specific (Austin *et al.* 1983). Efforts to maintaian latitude and altitude within strict

Table 1. Contingency table of the f_{obs} and f_{exp} for the Eragrostietosum (community no. 22).

Median Annual Rainfall (mm)

Altitude (m)		350-<375	375-<400	400<425	425-<450	450-<475	475-<500	500-<525
1200-<1300	f_{obs}	1	3	2	6*	0	0	0
	f_{exp}	0.4	2	1.6	4.4	0.4	2	1.2
1300-<1400		0	2	2	5 *	1	5	3
		0.6	3	2.4	6.6	0.6	3	1.8

Chi-square = 9.46970 D.f. = 6 Significance = 0.148835 n=30 * =36% of n

limits provides a valuable opportunity for testing the effect of changing other environmental factors. Werger (1980) provides data collected within narrow altitudinal (900-1100 m asl) and latitudinal (2°) limits.

Once the separation of plant communities has been achieved using floristic data, methods to further understand the relationship between the community classification and the associated environmental variable need to be employed. Two approaches are available. The first ordinates the environmental variables (Palmer *et al.* 1988) and the ordination diagram is interpretted. Co-variables can confound certain ordinations (principal component analysis), and with other methods (detrended correspondence analysis) the statistical treatment of the data is poorly understood (Wartenberg *et al.* 1987).

The second is a statistical approach (Austin *et al.* 1984) in which non-linear responses of natural communities are catered for by converting the explanatory variables into categorical variables, the class intervals being chosen to reflect the variation in the data (Austin *et al.* 1983). This approach has been described as concentration analysis (Feoli and Orlóci 1979, 1985, Orlóci and Kenkel 1987, Orlóci 1991). The application of a cross tabulation procedure to these classes provides basis for a contingency table, and the opportunity to test the null-hypothesis of independence.

If rainfall and altitude are not independent, the cells with the highest frequencies provide the conditions underwhich this community may occur. The potential distribution of the community, when projected as a digital map, provides a testable hypothesis of the potential vegetation.

There have been numerous efforts to model the associated environmental variables which contribute to the uniqueness of the community, and to use these to predict the community. This has, with few exceptions, only been successful in studies involving short gradient spans. The main reason being the lack of suitable data sets providing coverage both inside and outside a study area. Interpolated median annual rainfall (Dent *et al.* 1989) provides the first opportunity to model the plant communities and precipitation in southern Africa. Digital terrain models provide altitude for each sample.

Methods

Werger (1980) prepared a hierarchical classification

Table 2. Contingency table of the f_{obs} and f_{exp} for the Grewio-Rhoetalia erosae (community 25).

Median Annual Rainfall (mm)

Altitude (m)		425-<450	450-<475	475-<500	500-<525	525-<550	550-<575	575-<600	>600
1300-<1400	f_{obs}	1	6*	5*	8*	1	1	1	0
	f_{exp}	0.5	3.1	3.6	4.2	1.0	3.1	3.1	4.2
<1400		0	0	2	0	1	5*	5*	8*
		0.8	2.9	3.3	3.8	1.0	2.9	2.9	3.8

Chi-squared = 29.5893 D.f. = 7 Significance = 1.12924E-4 n=44 * =84% of n

Table 3. Contingency table of the f_{obs} and f_{exp} for the Oropetietosum of the Pentzietea globosae (community 21).

Altitude (m)		Median Annual Rainfall (mm) 300-<325	325-<350	350-<375	375-<400	400-<425	425-<450
1200-<1300	f_{obs}	2	11*	8*	9*	4	1
	f_{exp}	1.7	9.6	7	8.7	6.1	1.7
1300-<1400		0	0	0	1	3	1
		0.3	1.4	1	1.3	1.0	0.3

Chi-square = 11.5265 D.f. = 5 Significance = 0.0418841 n = 40 * = 70% of n

of the vegetation of the upper Orange river, South Africa. Using a synoptic table approach (Pignatti personal communication), the communities of Werger were re-tabulated, with the final units being roughly equivalent to the syntaxonomic rank of order (= Veld Type). I extracted altitude (ALT) and median annual rainfall (MAR) from the model XGRID (Dent *et al.* 1989) for 377 samples representing these communities. MAR and ALT were divided into classes at 25 mm and 100 m intervals respectively. Following the modified classification of Werger (1980), a cross tabulation was prepared for each community, providing frequencies for each cell. A contingency table was prepared and a chi-squared statistic obtained for each community. Where the null hypothesis of independence was rejected, cells with the highest frequencies were selected as the optimum conditions for each community until more than 60% of the samples were included. Where the null hypothesis was accepted, the cells with the highest frequencies were selected subjectively after assessment of the sample size and the validity of rejecting the community.

The overlap of MAR and ALT conditions necessitated the declaration of alternative vegetation types in the model, as well as xeric and mesic variations of some communities. The latter may not have been justified floristically, but warrant inclusion as they represent real differences in rainfall status.

The CCWR/XGRID data between 30°S 24°E and 31°S 5 26°E (1: 250,000 sheets Colesberg and Aliwal North) were classified into potential plant communities by locating all co-ordinates which satisfied those conditions. The hypothesis was tested by visual comparison of the digital map with the map prepared

Table 4. Contingency table of the f_{obs} and f_{exp} for the dry Pentzietea incanae (community 38).

Altitude (m)		Median Annual Rainfall (mm) 250-<275	275-<300	300-<325	325-<350	350-<375
1000-<1100	f_{obs}	0	2	0	0	0
	f_{exp}	0.1	0.8	0.7	0.2	0.2
1100-<1200		1	19*	21*	0	0
		1.1	17.3	14.6	4.3	3.8
1200-<1350		1	11*	6	8	7
		0.9	13.9	11.7	3.5	3.0

Chi-square = 28.3408 D.f. = 8 Significance = 4.13595E-5 n = 76 * = 67% of n

Table 5. Contingency table of the f_{obs} and f_{exp} for the Stachyo-Rhoetum (community 30).

Altitude (m)		Median Annual Rainfall (mm)						
		275-<300	300-<325	325-<350	350-<375	375-<400	400-<425	425-<450
1100-<1200	f_{obs}	3	4	4	3	0	0	0
	f_{exp}	2.1	4.3	3.3	2.7	2.3	2.9	2.7
1200-<1300		8*	14*	11*	10*	10*	4	1
		8.9	17.7	13.7	11.3	9.7	12.1	11.3
1300-<1400		0	4	2	1	2	11*	13*
		5.0	10.1	7.8	6.4	5.5	6.9	6.4

Chi-square = 56.5219 D.f. = 8 Significance = 9.64035E-8 n = 105 * = 73% of n

Table 6. Contingency table of the f_{obs} and f_{exp} for the Stipagrostion (community 46).

Altitude (m)		Median Annual Rainfall (mm)		
		250-<275	275-<300	300-<325
1000-<1100	f_{obs}	4*	5*	0
	f_{exp}	2.8	2.8	3.5
1100-<1200		4	3	8*
		4.6	4.6	5.8
1200-<1350		0	0	2
		0.6	0.6	0.8

Chi-square = 10.5156 D.f. = 4 Significance = 0.0325834 n = 26 * = 65% of n

Table 7. Contingency table of the f_{obs} and f_{exp} for the Themedetea triandrae (community 19).

Altitude (m)		Median Annual Rainfall (mm)					
		475-<500	500-<525	525-<550	550-<575	575-<600	>600
1300-<1400	f_{obs}	2	1	2	0	1	0
	f_{exp}	0.6	0.3	1.7	0.3	0.6	2.6
>1400		0	0	4*	1	1	9*
		1.4	0.7	4.3	0.7	1.4	6.4

Chi-square = 12.0167 D.f. = 5 Significance = 0.0345601 n= 21 * = 62% of n

by Acocks (1970).

Results

The chi-squared statistic for each community (Table 1-8) showed that altitude and median annual rainfall were dependent in all cases at the 95% level, except for the Eragrostietosum (Table 1) and the Osteospermetum (Table 8). Where the null hypothesis of independence was rejected, the cells with the highest frequency were subjectively selected and are indicated in each table. Where data were not dependent (Table 1 and 8), further data need to be collected, but as they contained valuable information they were still used to build the model. The model of potential vegetation (Figure 1) was developed from all these results.

Four thousand nine hundred and sixty six pixels (33,6% of total) were classified into potential vegetation in the 40,000 km^2 of the study area. The classified pixels are projected as a digital map (Figure 2). The vegetation structure and syntaxonomic nomenclature are defined in Table 9.

Discussion and Conclusions

The communities extend from the grasslands and grassy shrublands (Grewio-Rhoetalia and Stachyo-Rhoetum) in the east to the dwarf shrublands (Pentzietea incanae and Stipagrostion) in the west. The communities follow an east-west aridity gradient, with the median annual rainfall of samples ranging from 663 mm to 229 mm.

Relationships between the model of potential vegetation (Figure 2) and the Acocks map (Fig. 3) are discernable. The potential vegetation follows the course of the Orange river, including its tributaries the Caledon and Seekoei rivers. This corresponds with the geographical limits of the original study.

A similar analysis, not shown here, of total floristic data collected along a steep altitudinal gradient (Palmer 1988), supported the conclusion that altitude is location-specific. The fundamental difference between the sampling approaches of Werger (1980) and Palmer (1988) was that the former study was restricted to the narrow altitudinal gradient in the valley of the Orange

Table 8. Contingency table of the f_{obs} and f_{exp} for the Osteospermetum leptolobi (community 28).

Altitude (m)		Median Annual Rainfall (mm)				
		300-<325	325-<350	350-<375	374-<400	400-<425
1200-<1300	f_{obs}	2	3	13*	8*	4*
	f_{exp}	1.7	3.4	11.1	8.6	5.1
1300-<1400		0	1	0	2	2
		0.3	0.6	1.9	1.4	0.9

Chi-square = 4.91944 D.f. = 4 Significance = 0.295663 n=35 * =71.4% of n

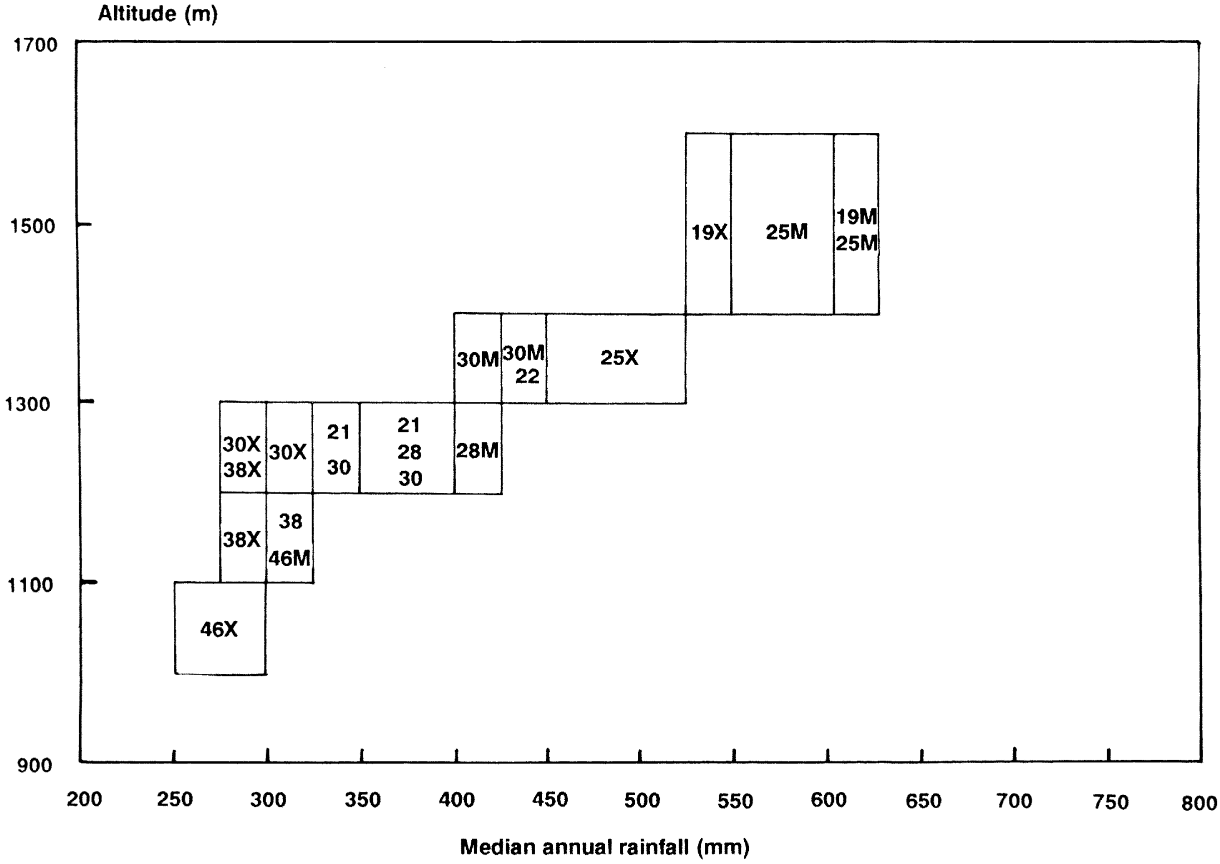

Fig. 1. Conditions of median annual rainfall and altitude associated with plant communities along the upper Orange river. See Table 9 for an explanation of the symbols.

river, whereas the latter ranged from 670-1700 m asl. I recommend that further efforts to collect data which will be used to build models of this nature should ado pt the Werger strategy.

Median annual rainfall is available for southern Africa and it is possible to model all the plant communities (at the level of order) in a similar manner, providing an objective basis for the separation of

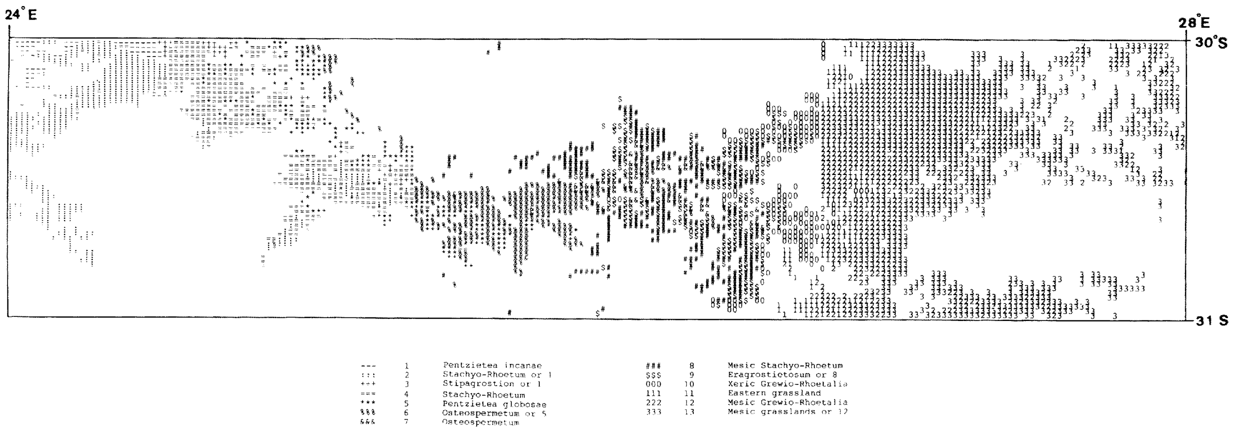

Fig. 2. Digital representation of the potential vegetation of the upper Orange river (30°S 24°E to 31°S 26°E). Determined from the median annual rainfall and altitude of described plant communities (Werger 1980).

Table 9. The potential vegetation, structure and syntaxonomic nomenclature for the model (X = xeric, M = mesic). Arranged in order of increasing aridity.

Comm. No.	Structure	Syntaxon (Werger 1980)
25M	Shrubland	Grewio-Rhoetalia
19M/25M	Grassland	Eastern grassland or
	Shrubland	Grewio-Rhoetalia
25X	Shrubland	Grewio-Rhoetalia
19X	Grassland	Eastern grassland
30M/22	Shrubland	Stachyo-Rhoetum of the Rhoetalia ciliata-erosae or
	Grassland	Eragrostietosum curvulae of the Hermannio coccocarpae-Nesterletum confertae
21/30	Dwarf shrubland	Pentzietea globosae or
	Shrubland	Stachyo-Rhoetum of the Rhoetalia ciliata-erosae
21/28/30	Dwarf shrubland	Pentzietea globosae or
	Shrubland	Stachyo-Rhoetum of the Rhoetalia ciliata-erosae or
	Shrubland	Osteospermetum leptolobi of the Rhoetalia ciliata-erosae
28M	Shrubland	Osteospermetum leptolobi of the Rhoetalia ciliata-erosae
30X	Shrubland	Stachyo-Rhoetum of the Rhoetalia ciliata-erosae
30M	Shrubland	Stachyo-Rhoetum of the Rhoetalia ciliata-erosae
38X	Dwarf shrubland	Pentzietea incanae
30X/38X	Shrubland	Stachyo-Rhoetum of the Rhoetalia ciliata-erosae or
	Dwarf shrubland	Pentzietea incanae
38/46M	Dwarf shrubland	Pentzietea incanae or
	Grassy dwarf shrubland	Stipagrostion

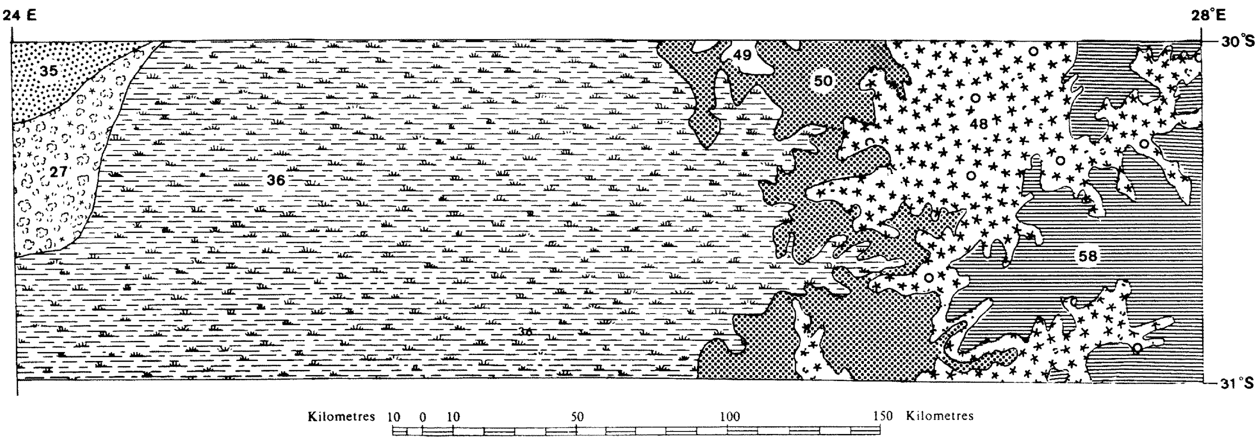

Fig. 3. The Veld Types of the Study area (Acocks 1988). 27 = Central Upper Karoo 35 = False Arid Karoo 36 = False Upper Karoo 48 = Cymbopogon-Themeda Veld 50 = Dry Cymbopogon-Themeda Veld 58 = Themeda-Festuca Alpine Veld.

potential vegetation types.

The model provides alternative vegetation types where substrate may be the differentiating factors. The Stipagrostion occurs on shallow soil of dolerite origin on the pediment, whereas the Pentzietea incanae occurs under the same MAR and ALT conditions, but on the pediment with soils derived from either mudstone or sandstone.

The boundaries and location of Acocks' veld types correspond with those of the potential vegetation based on altitude and rainfall. As this is a model of potential vegetation it would be unwise to try to validate the model by collecting further field data, as the contemporary vegetation patterns will probably not reflect those predicted by the model. It is intended to assess the extent to which the contemporary vegetation is degraded or deviates from the model by further investigating selected sites within each potential vegetation class.

A short-coming of the model is the large area of land represented by each pixel, namely 2.56 km^2, and the communities predicted by the model are not the only one's which will be present in a quadrant.

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