The shrubland vegetation of Adwa, northern Ethiopia

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A study of the vegetation of Adwa, Northern Ethiopia, was made to identify vegetation types and to relate the types identified to time of protection, physical and biological environmental factors, and to collect information for the decision support system. The vegetation data include binary and cover of the plant species encountered in 26 relevés collected according to the Braun-Blanquet approach. Multivariate numerical analyses of the data gave four vegetation types and 21 species groups. The vegetation types followed the altitudinal gradient ranging from 1500 m in river valleys to 2030 m on mountain ridges. The binary data set was found to be more informative than the cover data set. There is a direct correlation between length of protection time and species richness. The length of protection time has the same effects on the vegetation structure of different vegetation types. The recovery process of the vegetation begins with the increment in richness and cover of grass species. Then, after some years (3-5) shrubs and trees take over by depressing the grass component.

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Introduction

A long history of land clearing and sedentary agriculture has changed the vegetation cover in the highlands of Ethiopia. The natural vegetation of the northern and central Plateau of Ethiopia for example, may have been dry evergreen montane forest with *Juniperus procera* and *Olea europaea* subsp. *cuspidata* as the dominant species (Pichi-Sermolli 1957). It has disappeared from most parts except a few remnant patches around holy places and in inaccessible areas. Records of early European travellers in the fifteenth and sixteenth century (Almeida 1954; Alvarez 1970) indicate that the agro-climatic conditions were similar to those of the present day. The landscape then seems to have looked much like the present-day landscape, with the exception of the density of the trees in the crop fields; the number of trees was higher then than it is now.

The northern and central plateau of Ethiopia is characterised by mixed cereal and livestock agriculture. Nutrient deficient soils, high stocking rates and shortage of animal feeds are common features. As more land is cultivated to compensate for the diminishing soil fertility, and to meet the ever-increasing food demands, grazing is being pushed to very steep slopes and marginal lands.

In northern Ethiopia in general, and in Tigray in particular, government attempts mobilising the population to combat soil erosion and nutrient depletion. The activities to achieve these goals include adopting traditional indigenous methods of raising the fertility of the soil and terracing agricultural fields following contour lines and closing hill sides through participatory approach. These local improvements have created a suitable situation for estimating rates of recovery of the vegetation in the area. Some places have been protected for 15 years and have attained good vegetation cover, while others were protected for a quarter of a year. However, the majority of the sites visited have not been protected at all.

The objectives of the study were (1) to identify vegetation types, (2) to estimate the rate of recovery, and (3) to understand relation of the vegetation to environmental factors and anthropogenic influences.

Data collection

Sampling

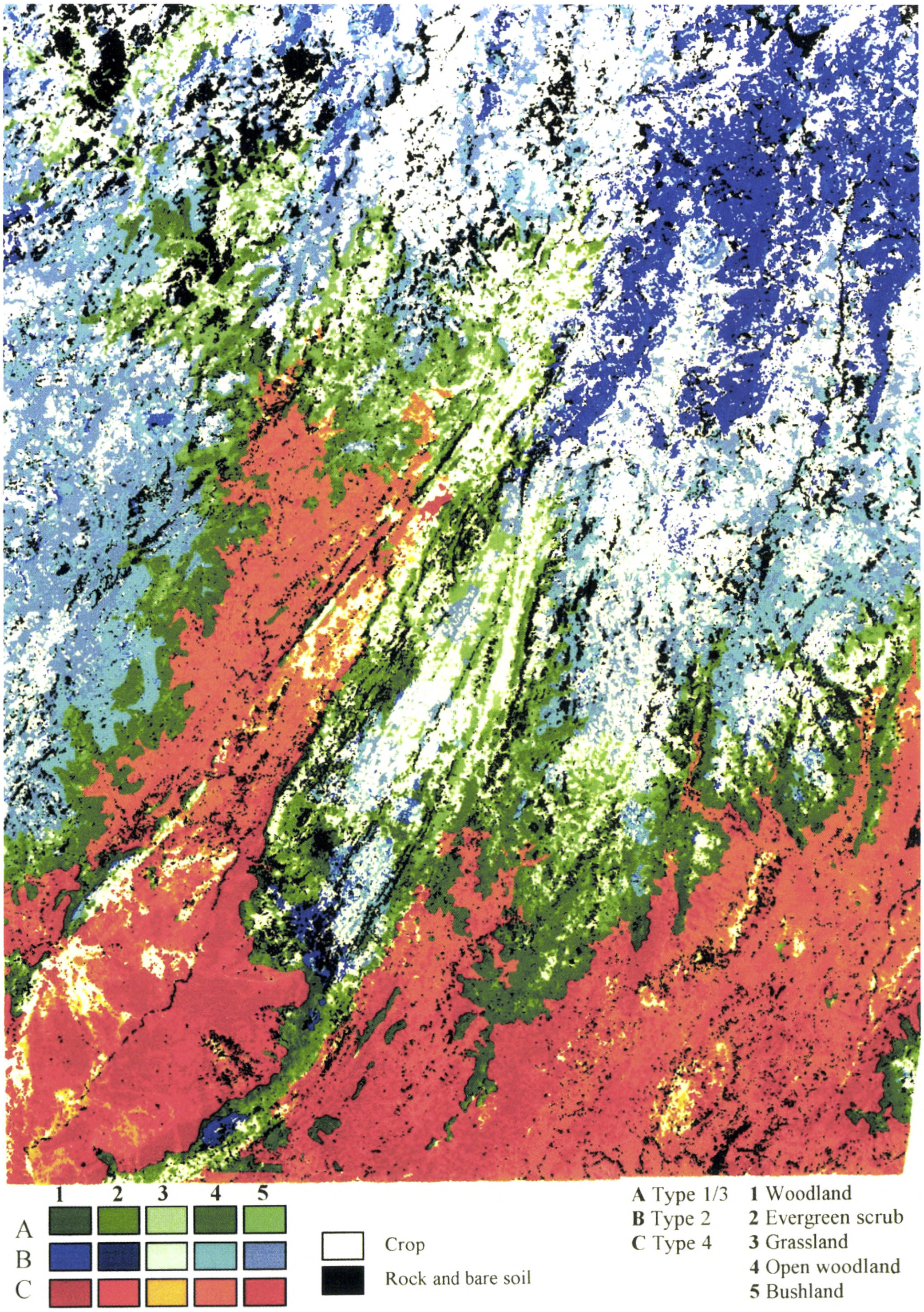
A reconnaissance survey was made in Adwa zone of Tigray Administrative Region in 1992 to select sampling points. This survey was conducted as the first phase of the Braun-Blanquet approach (Westhoff & Van der Maarel 1978). The activities during the survey included a visual inspection of the general vegetation pattern and an attempt to establish the apparent relations between vegetation and the environment. Sampling in this context would be essentially preferential (Orloci 1978). The preferential sampling approach was considered since it is believed to give the relevant information on several aspects of the vegetation in relation to management and physical environmental conditions. Moreover, the approach presumes to avoid redundancy and loss of time. Twenty-six relevés were sampled along the main road to the south from Adwa towards Weri River, which the road crosses approximately 40 km south of the town on the way to Abbi Adi. The Weri River is part of the Tacazze River system. The landscape is characterised by rounded mountain ridges (Fig. 1).

Environmental data

The following categories of environmental data were observed during the study:

GPS (Geographic Positioning System): The position of the relevé on the surface of the earth was observed. The observations were expressed both in degrees (geographic latitude and longitude) and in UTM kilometric co-ordinates. Every relevé has been geo-referred with a 12 meters precision by using a GPS receiver that calculates a position based on data coming from at least 3 of several orbiting satellites.

Fig. 1. Floristic-physiognomic vegetation types of the study area as analysed from a Landsat TM (1989) satellite image of the area south of the town of Adwa, towards the Weri River and Addi Abi, in part of the Adwa zone of Tigray Administrative Region. The ridges in the upper right corner, made up mainly of volcanic rocks, are characterised by vegetation type B (= type 2, with evergreen bushes, especially *Euclea* and sometimes *Dodonaea*). The middle level has the majority of the farmland in the area (indicated by white, signifying crops) and vegetation type B (= types 1 and 3; mainly vegetation with many weedy species). The river valleys, predominantly in the lower left corner, have cut into the rocks of the metamorphic basement complex and are characterised by vegetation type C (= type 4, dominated by short-lived grasses and annuals, whereas trees and shrubs, such as *Albizia amara* and *Becium filamentosum*, are not so common). Certain species, *e.g. Acacia etbaica* and *Becium filamentosum*, are freqent in all the vegetation types. Rocks, indicated by black, are common on the ridges and at the upper, steep edges of the river valleys. →


1
2
3
4
5
A
B
C
Crop
Rock and bare soil
A Type 1/3
B Type 2
C Type 4
1 Woodland
2 Evergreen scrub
3 Grassland
4 Open woodland
5 Bushland

Altitudes: This information was collected using a pressure altimeter and GPS. Altitudes in meters above sea level were scored.

Aspect and inclination: These measurements were made using a compass. The aspect was scored on a scale from 1 to 9. Inclination was degrees deviating from horizontal.

Parent material: this is the rock from which the soil or the colluvial deposits has been formed. The presence or absence of volcanic, metamorphic or sedimentary rocks were scored as 1 or 0.

Soil type: the morphologic description (form and colour). Further soil data of horizon A were also collected, but are not given in this paper; they are only utilised in a comparison in Table 4.

Erosion: the main erosive processes, like sheet wash (superficial elemental water flowing without a precise direction), rill-wash (water flows following precise directions, excavating furrows in the ground). Seepage and gullies were expressed by an ordinal scale (1 to 6) of erosion intensity that has been established by combining the different erosion characteristics.

Vegetation physiognomy: This refers to a description of the vegetation morphology such as: size of trees, shrubs, herbs and grasses, spatial distribution, cover of vegetation as projection on the soil. Cover of grasses and shrubs has been scored in percent; the height of the vegetation in cm.

Management: various land uses were identified: cultivated, grazed, enclosed, afforested; interviews with peasants were conducted to get an overview of the land use history in the past such as the age terraces and enclosed areas. Terracing was scored on a scale from 1 to 3; particularly important was the duration of protection, if any (scored as number of years protected.

The environmental data are given in Table 1.

Vegetation data

The vegetation relevés consists of the species list compiled on homogeneous surfaces of about 400 m^2. To each species a percentage of cover value was assigned by visual estimation. The relevés are shown in Table 2. This table is structures according to the results of clustering analysis of the binary data (presence =1; absence =0).

Analyses of the vegetation data

Multivariate methods of data analysis were applied to define vegetation types and to evaluate the correlation between vegetation types and environmental variables.

Classification of vegetation

The agglomerative method, complete linkage (Anderberg 1973) with similarity ratio (Westhoff & Van der Maarel 1978) as index of resemblance was applied both on the binary (presence-absence) and cover data. The species were classified by complete linkage clustering with correlation coefficient as index of resemblance applied on the cover data (Feoli *et al.* 1982). The original table was restructured based on the classification of the relevés and the species. The structured tables of species-groups and relevé-groups were subjected to analysis of concentration (AOC; Feoli & Orloci 1979). This technique gives the relationships between species groups and relevé-groups in a reduced multidimensional space by decomposing the total chi-square (χ^2) of a table in canonical variates.

Ordination of the vegetation

The relevés were ordered using the principal component analysis (PCA) and eigenvectors of the similarity ratio matrix (Feoli 1977) applied on the soil and other environmental data, and on the binary and cover vegetation data (EOB = Eigenvector Ordination of the Binary data, EOC = Eigenvector Ordination of Cover data)

Table 1. Environmental data of the 26 relevés (excluding soil data of A horizons).

Sedimentary rocks	Metamorphic rocks	Volcanic rocks	Aspect	Terracing	Erosion	Protection (yr)	Inclination	Stoniness	Vegetation height	Grass cover	Shrub cover	Irradiation	Altitude
0	0	1	3	1	2	0	25	50	200	10	35	298	1795
0	0	1	1	1	2	0	26	70	200	40	1	252	1805
0	1	0	3	2	2	1	25	20	300	100	5	298	1500
0	1	0	2	1	2	3	25	20	70	100	1	298	1500
0	1	0	3	3	2	0.25	4	25	80	90	40	312	1750
0	1	0	3	3	2	0.25	12	50	70	50	50	309	1755
0	1	0	3	1	2	3	25	80	100	40	15	298	1950
0	0	1	1	1	2	3	40	80	100	100	20	199	1950
0	0	1	2	2	2	0	25	50	70	20	5	271	1970
0	0	1	3	2	2	0	31	50	100	30	20	291	1990
0	1	0	5	3	2	0	22	80	100	5	15	317	1950
0	1	0	2	3	2	15	24	40	200	100	50	274	2030
0	1	0	7	3	2	0	33	20	200	5	5	288	1786
0	1	0	7	3	2	0	30	100	200	1	1	302	1810
1	1	0	7	1	2	0	25	100	100	5	35	298	1800
0	1	0	1	3	2	1	30	25	50	100	1	243	1790
1	1	0	3	1	2	0	32	50	300	50	1	290	1720
1	1	0	7	1	2	1.5	32	30	300	65	1	290	1700
1	1	0	3	1	2	1.5	30	20	300	100	1	302	1655
1	0	0	7	1	2	0	5	50	200	10	5	312	1870
1	0	0	8	1	2	2	8	80	30	60	10	303	1865
1	1	1	5	1	2	0	25	50	150	20	35	314	1950
1	1	0	3	1	2	3	20	80	250	50	5	303	1790
0	1	1	3	2	2	0	24	70	150	5	50	289	1750
0	1	1	1	1	2	0	25	50	150	40	0	259	1773
0	1	1	3	1	2	0	40	50	200	10	10	260	1780

respectively. This is expected to give the pattern of variation of the vegetation in the multidimensional ecological space (Feoli & Orloci 1991).

Correlation between vegetation and environment

Both the binary and cover data were considered in order to evaluate which of the two data sets is more correlated to environmental data. Predictivity was measured by *indirect* and by *direct* approaches (Feoli 1983).

The indirect approach

1. Mutual information and its decomposition in rows and columns (Feoli *et al.* 1982) of the table obtained by the centroids of vegetation clusters described by environmental data (Table 1) and those of the soil data of horizon A (not given here). The data were normalised by rows before the application of mutual information.
2. Autocorrelation following Feoli & Ganis (1989) for each of the environmental variable superimposed on EOB and EOC ordinations.

Table 2. Species/Relevé matrix arranged according to the sequence of the complete linkage clustering
Veg type: The four vegetation types. Spg.: The twenty-one species groups.

	Veg.type.	1						2						3						4							
Spg	Species/Relevés	20	23	19	25	10	14	6	7	8	9	11	15	21	24	1	2	12	13	4	5	22	3	3b	17	18	16
1	*Abutilon bidentatum*																							1			
	Aristida keniensis																							10			
	Aristida triticoides																							20			
	Tagetes minuta												1										1	50			
	Dichrostachys cinerea						1																	5			
	Commicarpus grandiflorus						1									1		1		2		2		10		1	1
	Becium filamentosum	1	1		1			2		1	1	1	2			1				2	1		2	10			
	Dicoma tomentosa								1								1			1			1	5			
	Flueggea virosa								1							1	1			2				5			1
	Chloris virgata			1									2				1					5	20	60	5	5	1
	Commiphora africana																						2	5			
	Cyathula orthacantha																						1	2			
	Digitaria velutina																2	1			2	2	20	30	10	1	1
	Striga hermontheca																						1	1			1
2	*Phyllanthus maderaspatensis*		1	1								1	1							1			1	1			
	Albizia amara																1						10	1	1	5	
	Cadaba farinosa																						1				
	Desmodium ospriostreblum																						1				
	Grewia villosa																						1				
	Hibiscus trionum																						1				
	Ipomoea sinensis																						1				
	Lannea schimperi																						1				
	Rhynchosia nyasica																						1				
	Guizotia schimperi														1						1		5				
	Senna italica																						2	1			
	Vernonia popeana											1											1				
3	*Setaria acromelaena*		1	1												1							2		1		1
	Achyranthes aspera											1	1			1					1	1	1		2	1	
	Bidens biternata																			1	1				20		
	Rhus natalensis																								1		
	Commicarpus ambiguus								2				1				1				1		1		5	1	
4	*Pennisetum nubicum*																			20		30			40		
	Bidens pilosa	2		2			1	2	1					1		5	2	1	1	1			5		20	60	1
	Boswellia papyrifera																									10	
	Combretum adenogonium																									1	
	Delphinium dasycaulon																									1	
	Terminalia brownii																									1	
	Gardenia lutea																									10	1
5	*Sida alba*		1													1				1					1	1	1
	Bidens macroptera		1			1				1	1	1	1		1						1	10					20
	Otostegia integrifolia																										1
	Ozoroa insignis																										1

	Veg.type.	1						2						3						4							
Spg	Species/Relevés	20	23	19	25	10	14	6	7	8	9	11	15	21	24	1	2	12	13	4	5	22	3	3b	17	18	16
6	*Cistanche phelipaea*																								1		1
	Grewia ferruginea																					1					
	Pennisetum pedicellatum																					1					
	Indigofera spicata																	1				5				1	
	Crotalaria plowdenii																					1	1				
7	*Zizyphus spina-christi*															1			1			1					
	Acacia etbaica	40	30	40	30		1	2		1	1	2	1	10	2	5	1	10	1	30	2	30	1	2	1		5
	Andrachne aspera	1	1																	1							1
	Bothriochloa insculpta	10							5			2	5							10	1						
	Heteropogon contortus	5	1						2			5	2							5	1	5					
	Leptochloa panicea	1																		1		1		1			
	Crotalaria spinosa	2															1										
	Gloriosa simplex	1															1										
	Cynodon dactylon	5		1		1	1		1							1	1	1									
	Monsonia angustifolia	1																									
	Periploca linearifolia	1																									
	Aloe sp.	1		5	1				1	1		1		1													
8	*Medicago polymorpha*	1		1		1			1			1				1	1	1				1					
	Brachiaria comata	5	1	1	1			1			1										15	1	1				
	Flaveria trinervia																				1						
	Indigofera brevicalyx																				1						
	Satureja simensis																				1						
	Rumex nervosus					1		1	5		1					1	1				50						1
	Cometes abyssinica																			1	1						
	Chenopodium ambrosioides																			1	1						
	Exotheca abyssinica																			1	1			1			
	Maytenus senegalensis																			1	1	1					
9	*Solanum nigrum*																1			1	1	1					
	Cynoglossum lanceolatum	1	1					1	1	1						1	1	1		10							5
	Justicia cordata																			1							
	Pseudognaphalium oligandra																			1							
	Xanthium spinosum																			1							
	Oxygonum sinuatum		1	1			1		1			1			1	1	1		1	10	1		1	2	1		
	Eragrostis tenuifolia	1						1	2	1	1					1				3	1						
10	*Eragrostis cilianensis*			1		1	1				1					1		1		2	1				1		
	Acacia oerfota																1										
	Chloris gayana																1										
	Galinsoga parviflora																1										
	Oxalis corniculata																1										
	Senna obtusifolia			1												2	10						1				
	Commicarpus helenae																1				1						
	Guizotia villosa										1						1										
	Croton machrostachyus						1		1								1								1		

	Veg.type.	1						2						3						4							
Spg	Species/Relevés	20	23	19	25	10	14	6	7	8	9	11	15	21	24	1	2	12	13	4	5	22	3	3b	17	18	16
11	*Oxalis obliquifolia*								1								1										
	Acacia seyal						1						1	1		1				1							
	Spermacoce chaetocephala	1	1	1	1		1						1	1	1	2	1			1	1		1				
	Acanthospermum hispidum															1											
	Cissus jatrophoides															1											
	Conyza tigrensis															1											
	Euphorbia indica															1											
	Hackelochloa granularis															1											
	Salvia merjamie															1											
	Thunbergia alata															1											
	Tribulus terrestris															1											
	Barleria acanthoides															5	1						2				
	Barleria eranthemoides		1		1	1	1	2				1				5							1	5			
	Tetrapogon cenchriformis	2	1							1	1		1		1	5	1	1		2	1		1				
	Polycarpaea eriantha					1										1											
	Commelina subulata															1	1										
	Trichodesma physaloides															1	1										
12	*Commicarpus pedunculosus*															1	1			1							
	Brachiaria deflexa		1			1	1				1					1					1					1	
	Galinsoga quadriradiata					1	1				1					1		1					1				
13	*Leucas martinicensis*					1	1				1	1		1		1	1	1	1	1			1		1	1	
	Dactyloctenium aegyptium		1								1			1	1	1	1	1		1		1	1		1		
	Senna occidentalis		1				1								20												
14	*Tragus berteronianus*	1	1	1	2		1				1		1		2	2	1	1		1		1			1	1	1
	Acokanthera schimperi						1																				
	Commelina velutina						1																				
	Sansevieria .sp						1																				
	Teclea nobilis						1																				
	Solanum schimperianum						5									1								1			1
	Cyphostemma molle					1	2				1											1					
	Kalanchoe lanceolata	1					1				1																
	Hypoestes forskolei	5	5	10	10	5	20		1		5		2	10	5			20		5	2				1	1	1
	Capparis tomentosa		1				1	1																			
	Evolvulus alisinoides		1				1									1	1		1								
15	*Oxalis radicosa*		1				1					1			1				1								
	Aerva javanica																	1	1	1	1						
	Argemone mexicana															1		1	1								
	Cerastium octandrum																	1	1								
	Geranium arabicum																	1	1								
	Plantago afra						1											1	1								
	Sonchus sp.						1						1					1	1								
	Plantago lanceolata												1				1	1	1								
	Anagalis arvensis														1			1									
	Eragrostis papposa																	1									
	Panicum atrosanguineum																	1									
	Tridax procumbens																	1									
	Zehneria scabra																	1									

	Veg.type.	1						2						3						4							
Spg	Species/Relevés	20	23	19	25	10	14	6	7	8	9	11	15	21	24	1	2	12	13	4	5	22	3	3b	17	18	16
16	*Sida ovata*									1								1									
	Anthemis tigreensis					1				1																	
	Arthraxon lancifolius					1																					
	Centella asiatica					1																					
	Ctenium concinnum					1																					
17	*Crassula alba*					1																					
	Actiniopteris radiata										1																
	Adhatoda schimperi										20																
18	*Sporobolus festivus*									1	1																
	Antopetitia abyssinica							2																			
	Boscia salicifolia							1																			
	Scleranthus annuus							2																			
	Echinops. sp							10	1					1		1	1		5								
	Argyrolobium arabicum							1	1																		
	Vermifrux abyssinica							2	2																		
	Otostegia fruticosa							1	1				1														
	Aristida adoensis	10	2	1	2	1	1	30	10	1	5		1		1	5	1	2	1	25	10	1	20	20		5	1
19	*Verbascum sinaiticum*							1	1							1				1							1
	Calpurnia aurea								10					5													
	Vigna membranacea								1					1													
	Cissus quadrangularis								2													1					
	Cyanotis barbata								1																		
	Hypoestes triflora								5																		
	Ruellia patula								5						1												
	Harpachne schimperi					1		1	5	1	2	1	1														
	Cymbopogon nardus								30	1	1	20	1	1													
	Rhynchelytrum repens							1	5			2	1											1	1		1
	Peristrophe paniculata			1					3			1				1	1										
	Indigofera costata								1			1	1									1					
	Conyza stricta							1	1		1	1								1							
	Plectranthus barbatus								1		1	1															
	Satureja punctata								1	1	1	1															
	Dyschoriste radicans	1	5			1	1		5		1							4									
	Maytenus arbutifolia	1	1		1	1	1		1	1		1		1		1						1					
	Senna singueana	5	5	5	10	5	5	5	15	5	2	2		5		5	2	1		1		1	1		1	1	1
	Cordia africana													1													
20	*Euclea schimperi*					10	10	10	20	10	20	20	5	40													
	Andropogon abyssinicus											2															
	Asparagus africanus											1															
	Cicer cuneatum											1															
	Clutia abyssinica											1															
	Gladiolus psittacinus											1															
	Osyris abyssinica											2															
	Pterolobium stellatum											2										1					
	Sporobolus africanus											1															
	Themeda triandra											2															
	Trifolium tembense											1															

	Veg.type.	1						2						3						4							
Spg	Species/Relevés	20	23	19	25	10	14	6	7	8	9	11	15	21	24	1	2	12	13	4	5	22	3	3b	17	18	16
20	*Eucalyptus camaldulensis*											5															
	Rhus retinorrhoea											5															
	Dodonea angustifolia								2		1	40	1														
	Ormocarpum trichocarpum				1					1		5	1	1		1											
	Clerodendrum myricoides										1	2	1														
	Clematis simensis											2										1					1
	Plumbago zeylanica								1			2								1	1						
	Helictotrichon elongatum											1						1									
	Satureja abyssinica							1	1		2							1	1								
	Pimpinella hirtella					1						1													1		
	Tragia brevipes								1			1													1		
	Polygala albida											1	1	1	1						1						
21	*Sida rhombifolia*										1	1	1					1			1			1			
	Aeschynomene abyssinica	1							1				2								1						
	Alysicarpus quartinianus												5								1						
	Eragrostis cylindriflora												1														
	Hyparrhenia anthistirioides												1														
	Lactuca.sp												1														
	Snowdenia minima												1														
	Vigna vexilata												1														
	Hyparrhenia polystachya							2					60								1	5					
	Zornia glochidiata												1							1							
	Tephrosia pumila			1						1		1	2		1	1		1									1
	Corchorus trilocularis							1		1			1										1				

The direct approach

1. Canonical correlation analysis (CCA) using the ordination axes of PCA as independent set of variables and EOC and EOB axes as dependent sets.
2. Autocorrelation of the position of vegetation types in the spaces given by PCA of environmental and soil data.

Computer packages

Ordinations, CCA, classifications and mutual information was done using the program packages FIVEPA (Feoli *et al.* 1991) and ARCVEG (Burba *et al.* 1992), chi-square (χ^2) was computed using program ACTUS (Estabrook & Estabrook 1989).

Results

Classification of the vegetation

The overall floristic similarity between the relevés of both the binary and cover data is high. In the first case the last level of dendrogram fusion (similarity ratio) was 0.02, while within the groups the last level ranged between 0.11 to 0.16. In the second case it was less than 0.001 and the last level within the groups ranged between 0.02 and 0.07. This result indicates that the relevés represent different environmental situations. Eighteen eigenvalues were necessary to get more than 80% of the total variation showing the heterogeneity of both the binary and the cover data.

Table 3. Analysis of concentration of the species groups and relevé groups of the binary data matrix

The clusters of relevés (the four vegetation types) are indicated above the table.

The clusters of the twenty-one species groups are indicated to the right of the table.

	1	2	3	4
1	4.95	6.81	5.57	21.35
2	1.65	0.83	2.48	11.76
3	0.00	7.92	3.96	23.76
4	5.66	2.83	8.49	15.91
5	4.95	9.90	2.48	12.99
6	0.00	1.41	4.24	9.55
7	20.63	14.03	12.38	11.14
8	4.95	4.95	2.97	15.59
9	12.73	14.14	14.14	15.91
10	2.20	3.30	11.00	2.48
11	7.57	4.08	16.31	4.37
12	23.10	13.20	26.40	17.33
13	26.40	9.90	33.00	22.28
14	18.90	6.30	8.10	5.40
15	1.52	2.28	17.52	1.14
16	9.90	1.98	0.00	0.00
17	0.00	17.33	4.95	0.00
18	6.60	20.90	11.00	7.43
19	9.90	27.62	7.82	5.08
20	0.90	15.30	2.70	3.04
21	1.80	15.30	2.70	4.73

The classification of the relevés of both the binary and the cover data gave four main clusters, indicated as columns in Table 2, while the classification of species gave 21 species groups, indicated as rows separated by double lines in Table 2.

The analysis of concentration (for binary data, Table 3) shows the concentration of species groups and the rank of species groups according to the decomposition of the total mutual information. The results of mutual information and AOC suggest that the classification of the vegetation based on binary data has a higher internal predictivity than the classification based on cover data (Feoli 1983). The relevé-groups obtained by binary data and cover data show good correspondence since almost 70% of the relevés reflect the same classification.

These groups of relevés represent four vegetation types as follows (see also Table 2):

Vegetation type 1: characterised by *Acacia etbaica, Cynodon dactylon, Hypoestes forskaoli,* and *Barleria eranthemoides.* It had a high concentration of species groups 7, 14 and 16. This vegetation type is similar to vegetation type 3, as clearly depicted in Figs. 1 and 2. The type occurs at the middle level of the study area at an altitudinal range between 1750 and 1850 m, mainly on sedimentary and metamorphic parent materials.

Vegetation type 2: characterised by *Euclea*

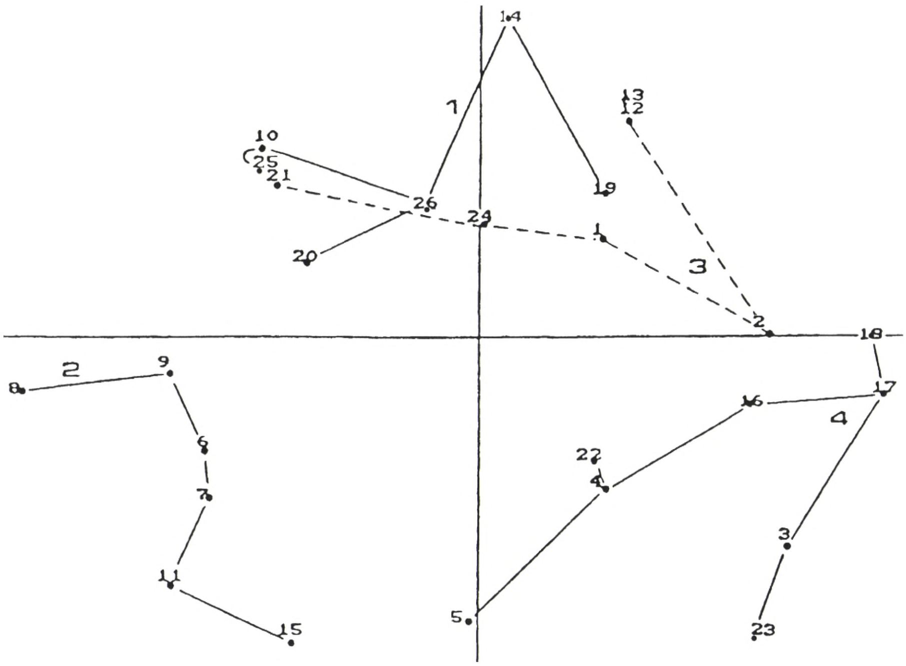


Fig. 2. The four vegetation types (indicated by the larger sized numbers 1-4) given by the binary data for the relevés (indicated by smaller numbers 1-26) superimposed on the 2nd and 3rd axes of the same data for the 26 relevés.

schimperi, Harpachne schimperi, Cymbopogon nardus, Dodonea angustifolia, and *Clerodendrum myricoides.* It had a high concentration of species groups 17, 18, 19, 20 and 21. This vegetation type occurs on the mountain ridges of the study area in the altitudinal range between 1850 and 2200 m, mainly on volcanic parent materials.

Vegetation type 3: characterised by *Senna obtusifolia* and *Dactyloctinium aegyptium.* The species groups with high concentration are 10, 11, 13 and 15. This vegetation type, like vegetation type 1, occurs at the middle level in the altitudinal range between 1750 and 1850 but mainly on volcanic and metamorphic parent materials.

Vegetation type 4: characterised by mani grasses, *e.g. Chloris virgata, Digitaria velutina, Pennisetum nubicum.* Trees, *e.g. Albizia amara* and occasionally *Acacia etbaica,* and shrubs, *e.g. Becium filamentosum,* are not prominent. It has a high concentration of species groups 1, 2, 3, 4, 5, 6 and 8. This vegetation type occurs where watercourses have cut down to the basement complex, and hence mainly on soils derived from metamorphic parent material, in the altitudinal range between 1500 and 1750 m.

Certain species, *e.g. Acacia etbaica,* is prominent in all the vegetation types. Each of these four vegetation types are divided into four physiognomic types each, as can be seen in unsupervised classification of the Landsat TM (1989) image (Fig. 1). The image also clearly shows how the vegetation types are associated with different types of landscapes in the area.

Ordination of the vegetation

The EOB and EOC (2^{nd} and 3^{rd} axes) show a rather well separated dispersion of the 4 vegetation types. However the ordination based on binary data shows a more clear separation between vegetation types (Fig. 2). The first two

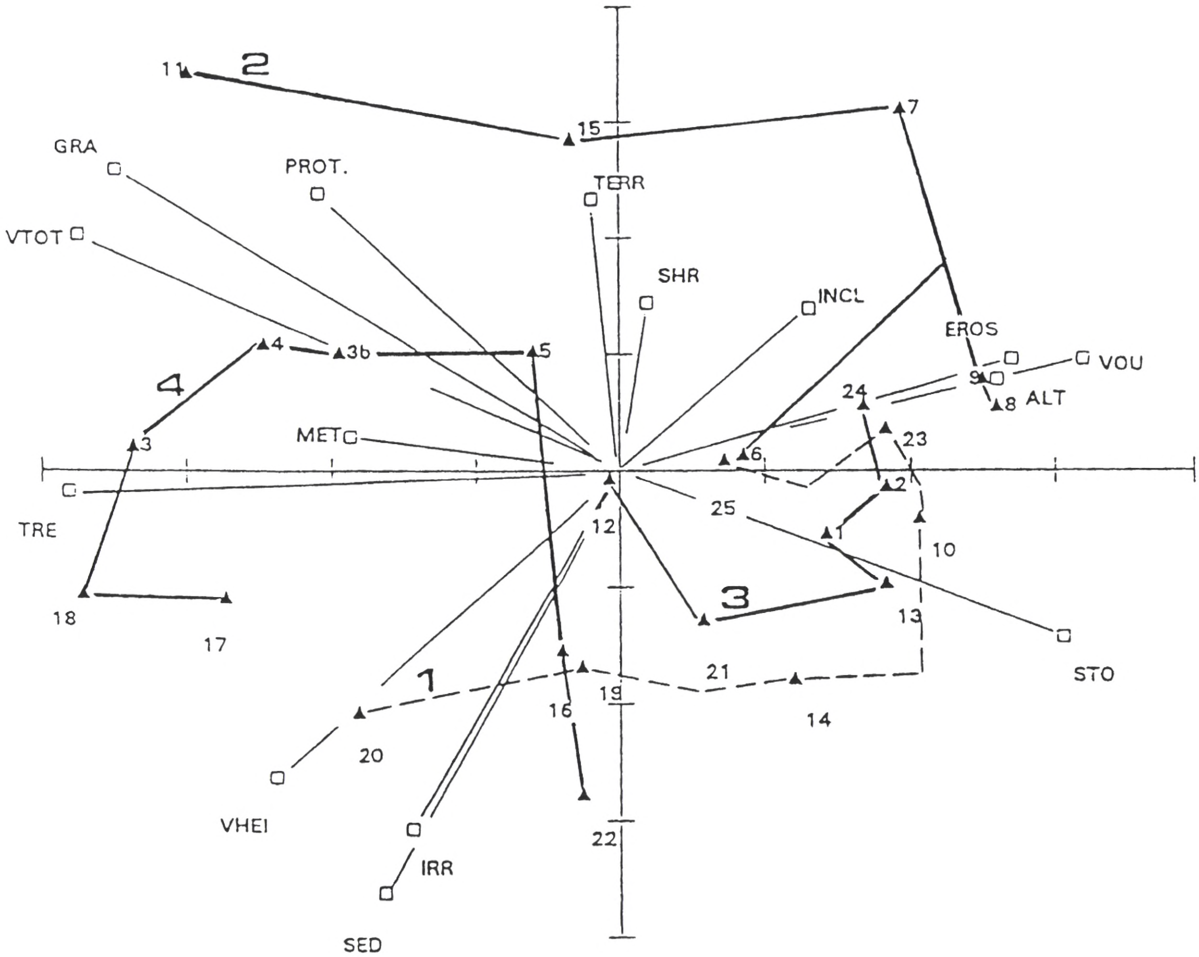


Fig. 3. The four vegetation types (indicated by the larger sized numbers 1-4) given by the classification of the binary data superimposed on the ordination of the 1st and 2nd axes of the environmental data (abbreviations in agreement with the data set in Table 1).

axes of PCA ordinations of the environmental data (Fig. 3) show the relevés of four vegetation types as being distinct. However within each vegetation type there are evident trends of variation mainly owing to erosion, stoniness, altitude, years of protection. The same applies for the further soil data (only horizon A) which were gathered during the study.

Correlation between vegetation and environment

From the decomposition of total mutual information of the groups, it appears that the predictivity of classification based on binary data (2I=354) is higher than the one based on cover data (2I=119). In both cases the most discriminating environmental variable is the length of time of protection, which is correlated with

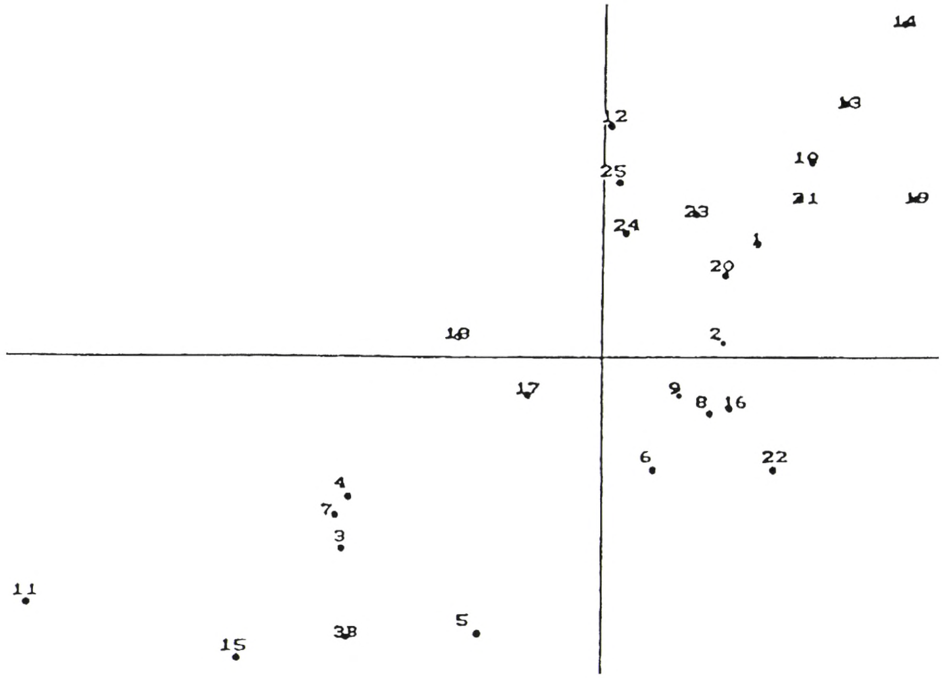


Fig. 4. Canonical correlation analysis of the environmental and the binary vegetation data for the 26 relevés.

the herb cover. The 2nd eigenvectors of the similarity matrices in EOB and EOC ordination show a gradient of protection decreasing from left to right. This separation is mainly due to altitude with type 2 having an average altitude of 1950 m and type 4 having 1670 m. The autocorrelation of environmental variables for EOB confirms the importance of altitude. In fact the autocorrelation shows significant aggregation for clay, altitude, pH, sand and protection (z=1.3). The autocorrelation of environmental variables for EOC shows significant aggregation only for altitude, sand, clay and grass-herb cover (z=1.2). This corroborates that EOB is more predictive than EOC.

The results of canonical correlation analysis (CCA, Fig. 4) also confirms that the predictivity of binary data is higher than that of cover data. In both cases the test of Bartlett (Feoli *et al.* 1991) is significant, however the one corresponding to EOB is higher than the one of EOC. The autocorrelation of the distribution vegetation types in the PCA ordinations based on environmental data and the soil data (only horizon A) mentioned above has shown that the aggregation is significant only for vegetation types 4 and 2 (Table 4a, b).

Conclusion

The vegetation of the study area is classified into four main vegetation types. These types are mainly influenced by altitude. There is a direct correlation between length of protection time and species richness. The length of protection time has the same effects on the vegetation structure of different vegetation types. However the grass species recovering at low altitude are different from those recovering at a higher altitude. The recovery process of the vegetation starts always with the increment in richness and cover of grass species. Then, after some years (3-5) shrubs and trees take over by depressing the grass component.

Table 4. Autocorrelation of the four vegetation types with environmental data and soil data. Spatial Autocorrelation for 26 relevés, 3 axes and Random H0 hypothesis.

Significance level	0.100	0.050	0.010	0.005	0.002
One tail Z test	1.282	1.645	2.326	2.576	3.090
Two tail Z test	1.645	1.960	2.576	2.813	3.291

(a) Environmental data	**Sum**	**Average**	**Observed values**	**Expected values**	**Z TEST**
Vegetation type 2	5.00	0.19	0.1331	-0.0400	3.1195
Vegetation type 4	5.00	0.19	0.1184	-0.0400	2.8546
Vegetation type 3	3.00	0.12	-0.0069	-0.0400	0.6145
Vegetation type 1	5.00	0.19	-0.0482	-0.0400	-0.1400
(b) Soil data					
Vegetation type 3	3.00	0.12	0.0281	-0.0400	1.4427
Vegetation type 2	5.00	0.19	0.0158	-0.0400	1.1664
Vegetation type 4	5.00	0.19	-0.0086	-0.0400	1.0161
Vegetation type 1	5.00	0.19	-0.0224	-0.0400	0.3692

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