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**Natural Resources Management
Within Multispecies Systems in
the Mid – Zambezi valley :
Implications for Sustainable Development in Dry Land Areas of
Southern Africa
(ZIMBABWE)**

CHARACTERISATION AND MAPPING OF VEGETATION COVER

Final report

By

Gérard DE WISPELAERE

CIRAD-EMVT report N° 01-32

May 2001

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SUMMARY : On three «Wards» of the Mid-Zambezi Valley, we have characterised vegetation from floristic observations made between 1997 and 2000. A factorial analysis followed by an image classification allowed the definition of a vegetation typology in eleven (11) classes, defined by discriminating species (ligneous and herbaceous).

A coverage of digital SPOT4 images, programmed for this project, provides information on the spatial distribution of the vegetation cover in function of the different soil types. The ecological analysis of the vegetation units compared to the spectral response of the field studied sites allowed to establish a set of 19 map units, characterised by the discriminating species, structure and soil types. The map of these classes is obtained by a series of image processing steps.

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1. Goal and objectives of study

The main goal of this study is to produce a detailed map of the vegetation cover for the three wards concerned by the project « Biodiversity Conservation in the Mid Zambesi Valley », and by the INCO-DC project funded by the European Union, i.e. Wards II, III et IV.

This mapping is based on the vegetation inventory that was carried out through field surveys, followed by the digital processing of SPOT Images.

To reach this goal, it was necessary to :

1. Geometrically rectify and geocode the images acquired for the project, and to assemble them in a mosaic with the geodesic reference of Zimbabwe;
2. Define a sampling protocol for the vegetation records;
3. Conduct a floristic inventory of the main vegetation types or the area;
4. Define the typology of vegetation formations by phyto-sociological analysis of the vegetation records;
5. Design a map nomenclature from the results of the field surveys ;
6. Elaborate a vegetation cover map from the SPOT data ;
7. Edit the map at 1:100 000 scale

2. Field surveys

The field trips were aimed at making an inventory of woody and herbaceous species of the project area through phyto-ecological records on the main landscape types of the area. These records were made through visual identification of recognisable species and physical sampling of the species unknown to the botanist.

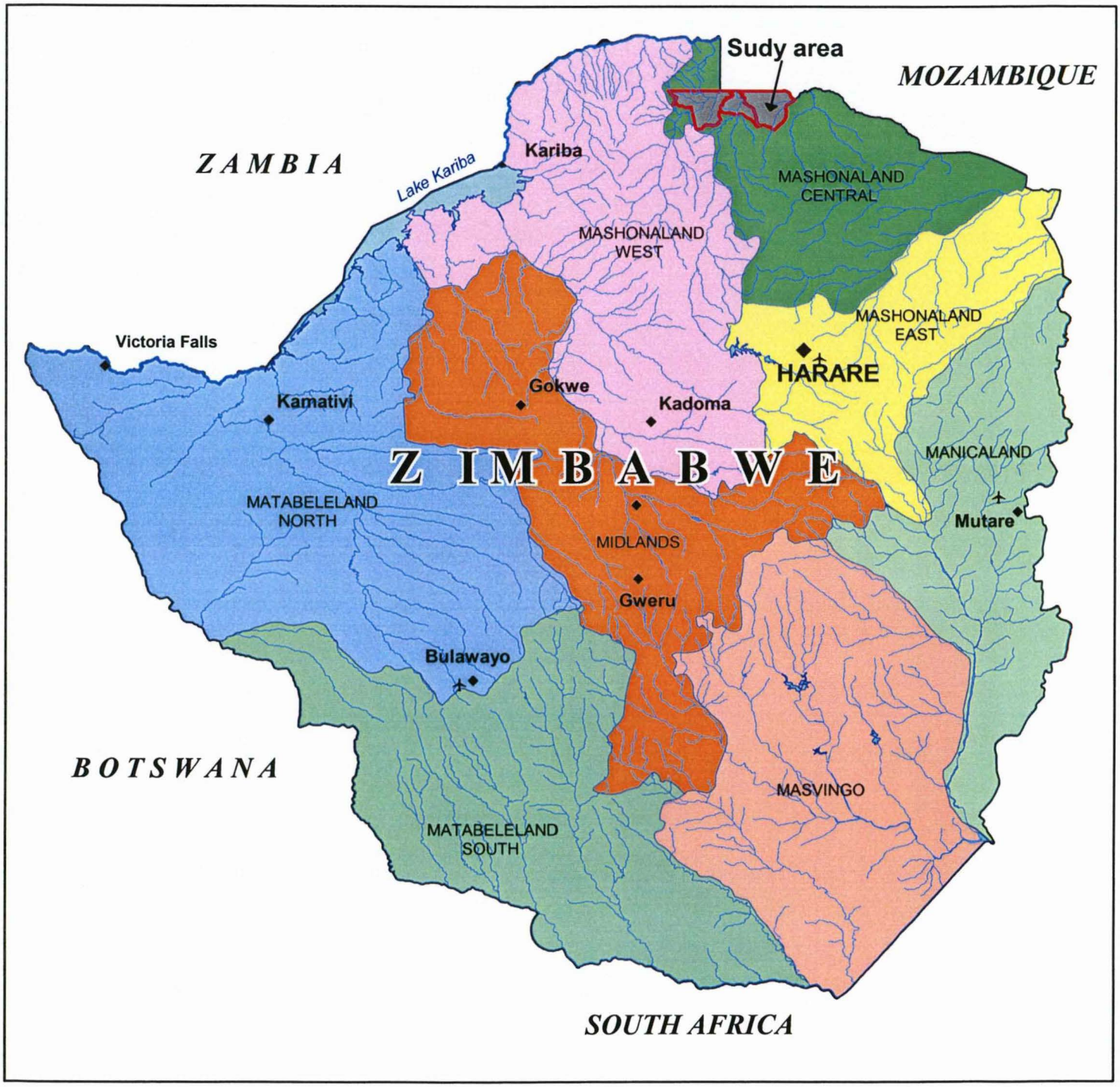
Two field trips were conducted from CIRAD headquarters in Montpellier to Zimbabwe for vegetation studies:

- From June 7th to 22nd, 1998
- From March 30th to April 14th, 1999

In addition to these field trips, two validation field trips were conducted by CIRAD staff posted in Zimbabwe:

- From May 31st to June 2nd, 2000
- From July 22nd to 25th, 2000

Fig.1 : Location of the study area



CIRAD-EMVT/ECONAP November 2000

2.1. Field trip preparation

Before making field observations, it was necessary to:

- Make a documentary study ;
- Prepare the satellite data (geometrically rectify and geocode, extract study area).

Two series of digital SPOT imagery were used, acquired in 1995 and 1999. To cover the entire study area, two scenes were necessary. For both dates, these were:

- 132-382 acquired on 13-07-1995 and 02-07-1999
- 133-382 acquired on 13-07-1995 and 02-07-1999

The SPOT satellite data was purchased at the raw processing level (1A) and were then geometrically rectified and assembled using ground control points (GCPs) extracted from 1:50 000 scale maps. These maps had been produced by the Surveyor General of Zimbabwe in 1978 from photogrammetric analysis conducted in 1959. Image processing was conducted at CIRAD-EMVT's Spatial Analysis Laboratory, at la Maison de la Télédétection in Montpellier.

2.2. Field observations

Because the first field trip took place in the dry season (June 7th to 22nd 1998), a complete inventory of the vegetation was not possible. In deed, the herbaceous stratum had been burned in many locations and, in most cases, their specie was unidentifiable.

The second field trip was conducted in the moist season (30 mars au 14 avril 1999), which allowed to collect 259 vegetation samples.

During the two field trips, 334 species were identified, of which 160 were for the ligneous stratum.

2.2.1. Participants

The 1988 field trip was conducted by :

DE WISPELAERE Gérard CIRAD-EMVT Geographer – Ecologist, specialist in Remote Sensing
VAGNINI Antoine, Geographer – cartographer, co-operation agent CSN .
CHIPORA Kambuzuma, N.C.O.- A.P.U.
CHITTIVA Movis, A.P.U. Sergeant
MAROYI Alfred, Research Officier, National Herbarium ;
MUZEZA Chris, Barefoot biologist ;
PAGIWA Naison, Barefoot biologist ;

The 1999 field trip was conducted by :

DE WISPELAERE Gérard CIRAD-EMVT Geographer – Ecologist, specialist in Remote Sensing
POILECOT Pierre , Biodiversity Conservation Programme in the Mid-Zambezi Valley, Botanist (April 4, 5 and 10-12, 1999)
DULIEU Dominique , CIRAD-EMVT , Ecologist (April 10 and 11, 1999)
MUZEZA Chris, Barefoot biologist (April 6 and 12, 1999).

The plants that were collected in the field were identified by Pierre POILECOT with the support of specialists of the National Herbarium.

Validation surveys were conducted by POILECOT Pierre et LAFAGE Bruno, Geographer-Cartographer, Co-operation agent CSN (from 31-05 to 2-06-2000 and 22 to 25-07-2000).

2.2.2. Field survey methods

The field observation sites were selected through "reasoned choice" after a cross-stratification between different layers of information available over the principal roads and tracks.

- Informations from the vegetation map by J.R. Timberlake, N. Nobadanda, I. Mapaure 1993, digitized and integrated in a GIS by the staff of the " Biodiversity Conservation Project "

- Geomorphological data also digitised and integrated in the GIS

- A Colour composite from the SPOT image of 1995, displaying the SPOT XS3 (near infrared) in Red, XS4 (middle infrared) in green, XS2 (red) in blue, in function of the classical principal of the" False colour composite " ; (figure 2). The observations were written on the Vegetation Survey Form (see example in Annex 1)

During both field trips, 45 records were made (24 in 1998 and 21 in 1999). This being insufficient to make a reliable map of the study area, the observations of J. Timberlaye et al. ,1998 were, with the authors' consent, included in our analysis.

In addition to these detailed vegetation records, our vegetation study also considered 52 records that were made in June and July 2000 through rapid appraisal methods. The inventory surface covers approximately 1 ha (100 m x 100 m) in an area that is as homogenous as possible. The ligneous and herbaceous species are identified and then coded using two tables of cover and height.

cover ranges			
0	-	5	10 to 25
1	< 0,5	6	25 to 50
2	0,5 to 1	7	50 to 75
3	1 to 5	8	75 to 90
4	5 to 10	9	> 90

Scale for height of vegetation			
0	0 to 5 cm	5	1 to 2 m
1	5 to 10 cm	6	2 to 4 m
2	10 to 25 cm	7	4 to 8 m
3	25 to 50 cm	8	8 to 16
4	0.5 m to 1 m	9	> 16 m

We also estimated the total cover of the ligneous stratum, of the herbaceous stratum and of bare soils. Each observation is georeferenced in x, y, in the cartographic systems ARC50 and UTM 36 South (cf. annexe 1). Photographs were taken of the most characteristic types.

2.2.3. Terminology

The structure and cover of vegetation considerably influence the spectral response recorded by the satellite's sensor. When elaborating the vegetation map using spatial data, it is therefore necessary to describe the vegetation formations with physionomical types that integrate the concepts of structure and cover.

In this study, we used a nomenclature inspired of the Yagambi (Aubreville, 1957) whcih was further precised by (Boudet, 1977) and adapted in Namibia by (Sweet, 1998) . We have 9 types of vegetation cover :

- Grassland : Gr
- Shrubbed grassland : Sgr
- Wooded grassland : Wgr
- Shrubland : Sh
- Wooded shrubland : Wsh
- Shrubbed woodland : Shw
- Woodland : Wl
- Forest : Fr
- Cropland : C

To theses main types, we added :

- Riparian forest : Rf
- Thicket : Th
- Fallow : Fw

These vegetation types can be characterised by the following attributes :

Open, dense, tall

"Shrubland" and "bushland" are synonymous terms, but we prefer the term "Shrubland" because it is more commonly used within the international community.

Figure 2 : Vegetation cover types

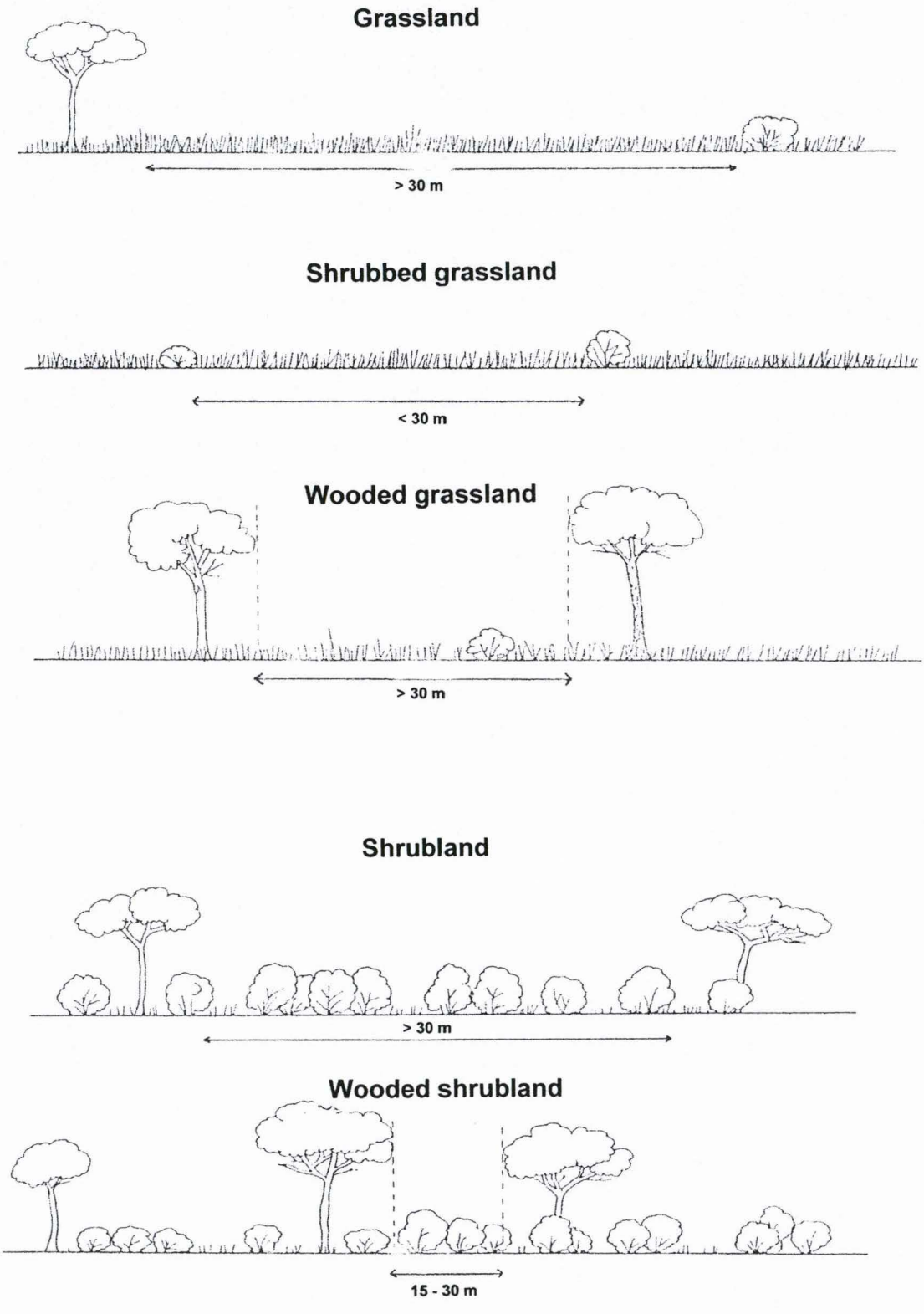
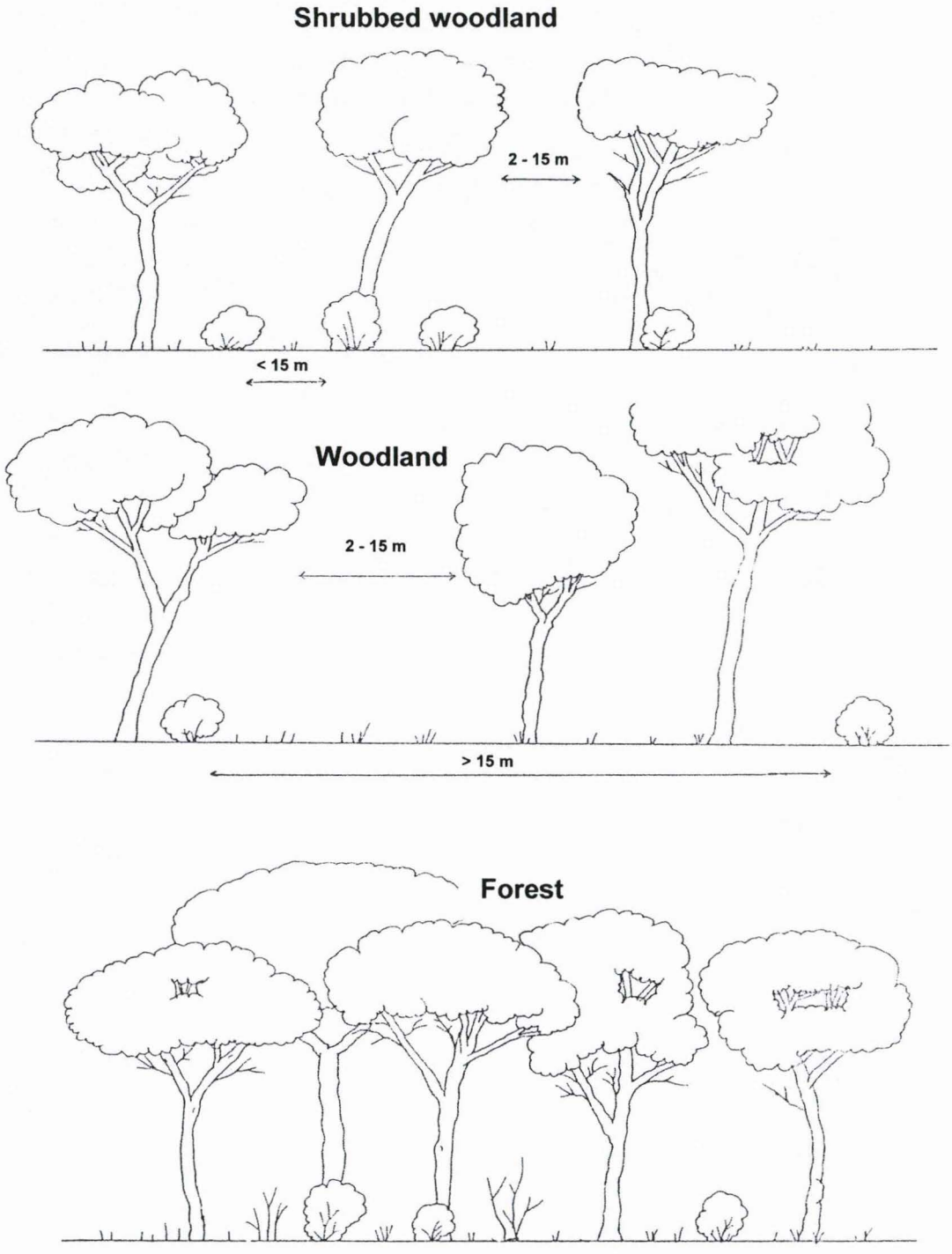


Figure 3 : Vegetation cover types (continued)



2.3 Results of field surveys

Table 1: location of the 1998 records and types of vegetation cover

Ref. Rel.	Auteurs	Date	ARC 1950 UTM 36 S		Couverts végétaux
			Y (m)	X (m)	
R01	GDW/AV*	12-june-98	8226440	223158	Fallow
R02	GDW/AV	12-june-98	8226424	223173	Fallow and grassland
R03	GDW/AV	12-june-98	8225253	224693	Dry forest
R04	GDW/AV	13-june-98	8224195	226847	Dry forest
R05	GDW/AV	13-june-98	8224430	226765	Open dry forest
R06	GDW/AV	14-june-98	8225049	250763	Shrubland
R07	GDW/AV	14-june-98	8225818	250755	Open woodland
R08	GDW/AV	14-june-98	8227234	246553	Woodland
R09	GDW/AV	15-june-98	8228029	272192	Open shrubland
R10	GDW/AV	15-june-98	8228430	276474	Open forest
R11	GDW/AV	15-june-98	8228320	273932	Open shrubland
R12	GDW/AV	16-june-98	8224099	269570	Thicket
R13	GDW/AV	16-june-98	8220499	260817	Open shrubland
R14	GDW/AV	16-june-98	8209686	258674	Woodland
R15	GDW/AV	16-june-98	8214486	256324	Grassland
R16	GDW/AV	17-june-98	8226180	212591	Open shrubland
R17	GDW/AV	17-june-98	8226056	212493	Forest
R18	GDW/AV	17-june-98	8226056	212493	Thicket
R19	GDW/AV	17-june-98	8223026	212493	Thicket
R20	GDW/AV	17-june-98	8221375	211328	Open woodland
R21	GDW/AV	17-june-98	8215767	215339	Shrubby woodland
R22	GDW/AV	18-june-98	8218439	223662	Mixt shrub on grassland
R23	GDW/AV	18-june-98	8218795	227960	Dry forest
R24	GDW/AV	18-june-98	8224413	231595	Open woodland

Table 2 : Location of the 1999 records and vegetation cover types

Ref. Rel.	Auteurs	Date	ARC 1950 UTM 36 S		Couverts végétaux
			Y (m)	X (m)	
R04	PP/GDW/DD	09-APR-99	8224195	226847	Dry forest
R13	GDW/CM	07-APR-99	8220477	260811	Shrubland
R16	PP/GDW/DD	10-APR-99	8226180	212591	Shrubland
R25	PP/GDW	03-APR-99	8221216	275282	Shrubland
R26	PP/GDW/CM	03-APR-99	8221291	275272	Shrubland
R27	PP/GDW/CM	03-APR-99	8220629	275441	Shrubbed woodland
R28	PP/GDW/CM	03-APR-99	8219823	275806	Shrubland
R29	PP/GDW/CM	04-APR-99	8225843	270608	Shrubland
R30	PP/GDW/CM	04-APR-99	8226275	271128	Thicket

R31	PP/GDW/CM	04-APR-99	8224477	273168	Woodland
R32	PP/GDW/CM	05-APR-99	8221236	271364	Grassland
R33	PP/GDW/CM	05-APR-99	8220033	271487	Shrubland
R34	PP/GDW/CM	07-APR-99	8224135	269537	Thicket
R35	GDW/CM	07-APR-99	8226841	266156	Wooded shrubland
R36	GDW/CM	08-APR-99	8211466	246330	Woodland
R37	PP/GDW/DD	10-APR-99	8224640	212825	Thicket
R38	PP/GDW/DD	10-APR-99	8219919	211260	Thicket
R39	PP/GDW/DD	11-APR-99	8223815	254831	Woodland
R40	PP/GDW/DD	11-APR-99	8225342	249948	Shrubland
R41	PP/GDW/DD	11-APR-99	8225420	249960	Grassland
R42	PP/GDW	12-APR-99	8215504	260640	Shrubland

* GDW : Gérard DE WISPELAERE , AV : Antoine VANINI , PP : Pierre POILECOT, DD : Dominique DULIEU , CM : Chris MUZEZA.

Table 3: Location of the records of J. Timberlake, 1998 and vegetation cover types

Ref. Rel.	**Auteurs**	**Date**	**ARC 1950 UTM 36 S**		**Couverts végétaux**
			Y (m)	**X (m)**	
R95a	JT*	2 May 97	8220770	243110	Woodland B1
R95b	JT	2 May 97	8220770	243110	Woodland B1
R96	JT	2 May 97	8224050	240800	Cropland B1b
R97	JT	2 May 97	8224340	240170	Cropland B1b
R98	JT	2 May 97	8223730	246210	Shrubland C1
R99	JT	2 May 97	8220940	254530	Shrubland C1
R100	JT	3 May 97	8221580	261220	Wooded shrubland A3
R101	JT	3 May 97	8222370	262040	Wooded shrubland A3
R102	JT	3 May 97	8226800	265600	Dry forest A3
R103	JT	3 May 97	8228160	266260	Wooded shrubland A3
R105	JT	3 May 97	8225600	263320	Dry forest A1
R106	JT	3 May 97	8226160	248620	Shrubland C1
R107	JT	3 May 97	8228280	245060	Dry forest A1
R108	JT	4 May 97	8217570	226060	Wooded shrubland B3
R109	JT	4 May 97	8218950	227940	Dry forest A1
R111	JT	4 May 97	8223700	227390	Dry forest A1
R114	JT	4 May 97	8227190	229460	Woodland B3
R115	JT	4 May 97	8226600	229010	Woodland B3
R118	JT	5 May 97	8213120	225480	Shrubland C1
R119	JT	5 May 97	8211720	221850	Riparian forest B1
R120	JT	5 May 97	8210420	217840	Woodland B3
R121	JT	5 May 97	8203430	213620	Woodede shrubland C3
R122	JT	5 May 97	8201250	212020	Woodland B3
R123	JT	5 May 97	8204080	207660	Woodland B3
R125	JT	6 May 97	8218260	217220	Woodland C2
R126	JT	6 May 97	8216000	204600	Woodede shrubland C4
R127	JT	6 May 97	8215900	198570	Woodede shrubland C4

R128	JT	7 May 97	8213730	207260	Riparian forest B1
R129	JT	7 May 97	8213960	207370	Riparian forest B1
R130	JT	7 May 97	8221670	211890	Thicket A2
R131	JT	7 May 97	8229770	212560	Shubbed woodland
R132	JT	7 May 97	8222980	212080	Dry forest A2
R133	JT	8 May 97	8211430	243750	Woodland B3
R134	JT	8 May 97	8205740	244820	Woodland B3
R135	JT	8 May 97	8204150	258120	Woodland C2
R136	JT	8 May 97	8220810	240090	Woodland C2
R137	JT	8 May 97	8227960	236820	Woodland C2
R139	JT	8 May 97	8224810	228890	Dry forest A1
R141	JT	8 May 97	8223810	228970	Dry forest A1
R142	JT	8 May 97	8223350	229150	Dry forest A1
R144	JT	8 May 97	8218280	226680	Dry forest A1

* JT : Jonathan TIMBERLAKE

The units A1, B3 etc. refer to the types of vegetation of the 1: 500 000 scale map by J. Timberlake 1998 with the following signification :

A1 : Dense *Xylia* on sand
A2 : Dense mixed – *Xylia* dry forest on shallow , gritty sands
A3 : *Terminalia Brachystemma* wooded bushland

B1 : Riparian woodland on recent alluvium
B1b : Cultivated fields and fallows on recent alluvium
B2 : Dry forest /bushland on old alluvium and in gullies
B2b : Fields and fallows bushland mosaic on old alluvium and colluvial fans
B3 : Tall mopane woodland on old, fine textured alluvium

C1 : *Diopyros kirkii / Combretum apiculatum* low open woodland on shallow soils
C2 : Low open mopane woodland on deeper, depositional soils
C3 : Mosaic of *Brachystegia allenii*/mopane open woodland on stony and deep soil
C4 : *Julbernardia* / *Combretum* /mopane woodland on rocky sandstone slopes
C5 : : Escarpment woodland

Table 4 : Location of the 2000 validation records and types of vegetation cover

Ref. Rel.	**Authors**	**Date**	**ARC 1950 UTM 36 S**		**Vegetation cover types**
			Y (m)	**X (m)**	
C1	PP/BL*	23/07/00	8226370	272341	Shrubland
C2	PP/BL	22/07/00	8223383	246774	Thicket
C3	PP/BL	22/07/00	8225616	248700	Woodland
C4	PP/BL	22/07/00	8228603	240773	Open shrubland
C5	PP/BL	22/07/00	8228268	242811	Jesse bush
C6	PP/BL	22/07/00	8228212	244402	Jesse bush
C7	PP/BL	22/07/00	8221540	253864	Old fallow

C8	PP/BL	22/07/00	8222880	254841	Old fallow
C9	PP/BL	22/07/00	8219697	255008	Shrubland
C10	PP/BL	22/07/00	8219893	254171	Woodland
C11	PP/BL	22/07/00	8218971	260116	Open jesse bush
C12	PP/BL	22/07/00	8219195	265112	Shrubland
C13	PP/BL	23/07/00	8219614	270136	Shrubland
C14	PP/BL	25/07/00	8227012	270052	Woodland
C15	PP/BL	23/07/00	8227542	265949	Dense jesse bush
C16	PP/BL	23/07/00	8228547	275216	Woodland
C18	PP/BL	23/07/00	8223913	273094	Opens jesse bush
C19	PP/BL	23/07/00	8221679	273206	Shrubland
C20	PP/BL	23/07/00	8220004	273038	Woodland
C21	PP/BL	24/07/00	8221791	191258	Woodland
C22	PP/BL	24/07/00	8222266	192068	Woodland
C23	PP/BL	24/07/00	8227012	190030	Woodland
C24	PP/BL	24/07/00	8222182	212331	Thicket
C25	PP/BL	24/07/00	8220898	210685	Shrubland
C26	PP/BL	24/07/00	8218022	209373	Shrubland
C27	PP/BL	24/07/00	8214895	214648	Woodland
C28	PP/BL	24/07/00	8225030	190979	Woodland
C30	PP/BL	24/07/00	8210959	215765	Open woodland
C31	PP/BL	24/07/00	8208139	206358	Woodland
C32	PP/BL	24/07/00	8212076	223524	Shrubland
C34	PP/BL	24/07/00	8219446	231423	Woodland
C35	PP/BL	24/07/00	8222740	227934	Open woodland
C36	PP/BL	24/07/00	8218943	232121	Shrubland
C37	PP/BL	22/07/00	8217464	235330	Shrubland
C38	PP/BL	23/07/00	8221596	274016	Gonono bush
C42	PP/BL	22/07/00	8223383	239182	Riparian forest
C43	PP/BL	24/07/00	8221400	239573	Woodland
C44	PP/BL	20/07/00	8224164	233461	Open thicket
C45	PP/BL	20/07/00	8224751	232846	Shrubland
C46	PP/BL	22/07/00	8223690	234661	Dense thicket
C47	PP/BL	22/07/00	8221903	250152	Thicket
C50	PP/BL	31/05/00	8219027	201510	Woodland
C51	PP/BL	31/05/00	8218949	201369	Woodland
C52	PP/BL	31/05/00	8221167	191483	Woodland
C53	PP/BL	31/05/00	8223045	206526	Woodland
C54	PP/BL	01/06/00	8212934	225367	Shrubland
C55	PP/BL	01/06/00	8211418	220848	Woodland
C56	PP/BL	01/06/00	8207220	214810	Woodland
C57	PP/BL	01/06/00	8201784	212772	Woodland
C58	PP/BL	01/06/00	8218735	262930	Woodland
C59	PP/BL	01/06/00	8218587	266103	Gonono bush

* PP : Pierre POILECOT – BL : Bruno LAFAGE

Finally, 83 complete records and 59 control points were used for the vegetation study, for a total of 142 records.

3. Analysis of the vegetation data

The data resulting from the field observations were integrated in a database (EXCEL spreadsheet) for the phyto-sociological analysis.

3.1 Making observations compatible

Because the records were made by authors of different organisations, the evaluation methods, based on visual estimations, differ in their coding of the relative frequency of species.

J. Timberlake codes species in the following manner :

+ : present
d : dominant or abundant
f : frequent
r: rare

CIRAD scientists have used a more detailed method with an estimation of abundance and cover by specie (cf. 2.2.2. field survey methods).
For the data analysis, it was necessary to "homogenise" the codes. Because it was impossible to further detail the observations by J. Timberlake, we simplified the observations by CIRAD staff and the species in all records were coded in three classes:

1 : present
2 : frequent
3 : abundant and/or dominant

The detailed list of plants (Poilecot, 2000) contains 796 species of which many exist in only one record, because they are rare or are visible only during a short period.

During analysis, to integrate the records made during the dry season, it was necessary to render the observations coherent within both seasons. We therefore removed, from the moist season records, the herbaceous species that were not visible during the dry season.

These two simplifications considerably reduced the number of species considered in the analysis, leaving only 131 common species for the 142 records.

3.2 Data analysis methods

The vegetation record data was processed by factorial analysis using the program ADE4[1]. A Principal Component Analysis (correlation matrix PCA) was first conducted, followed by a Ascending Hierarchical Classification (ACH), using the record numbers as variables.

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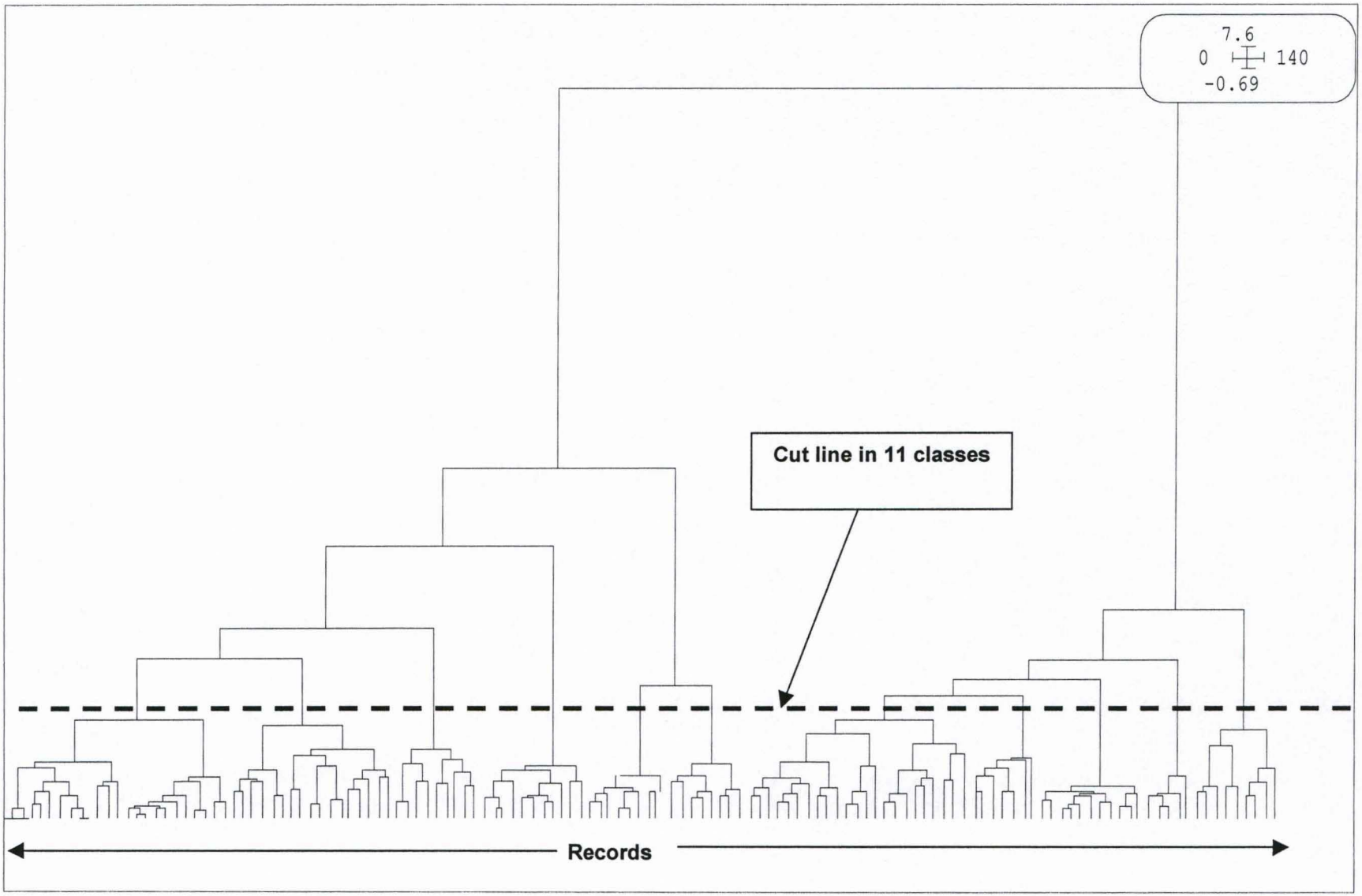
[1] ADE4 : Analyses des Données Écologiques : méthodes Exploratoires et Euclidiennes en sciences de l'Environnement

Figure 4 : ACH Dendrogram of the records



The separation into 11 classes allows the establishment of a robust vegetation typology which is more detailed than what had been previously defined. Figures 4 and 5 present the clouds of the records in the factorial axes 1-2 and 1-3.

Figure 5 : Axes F1 – F2

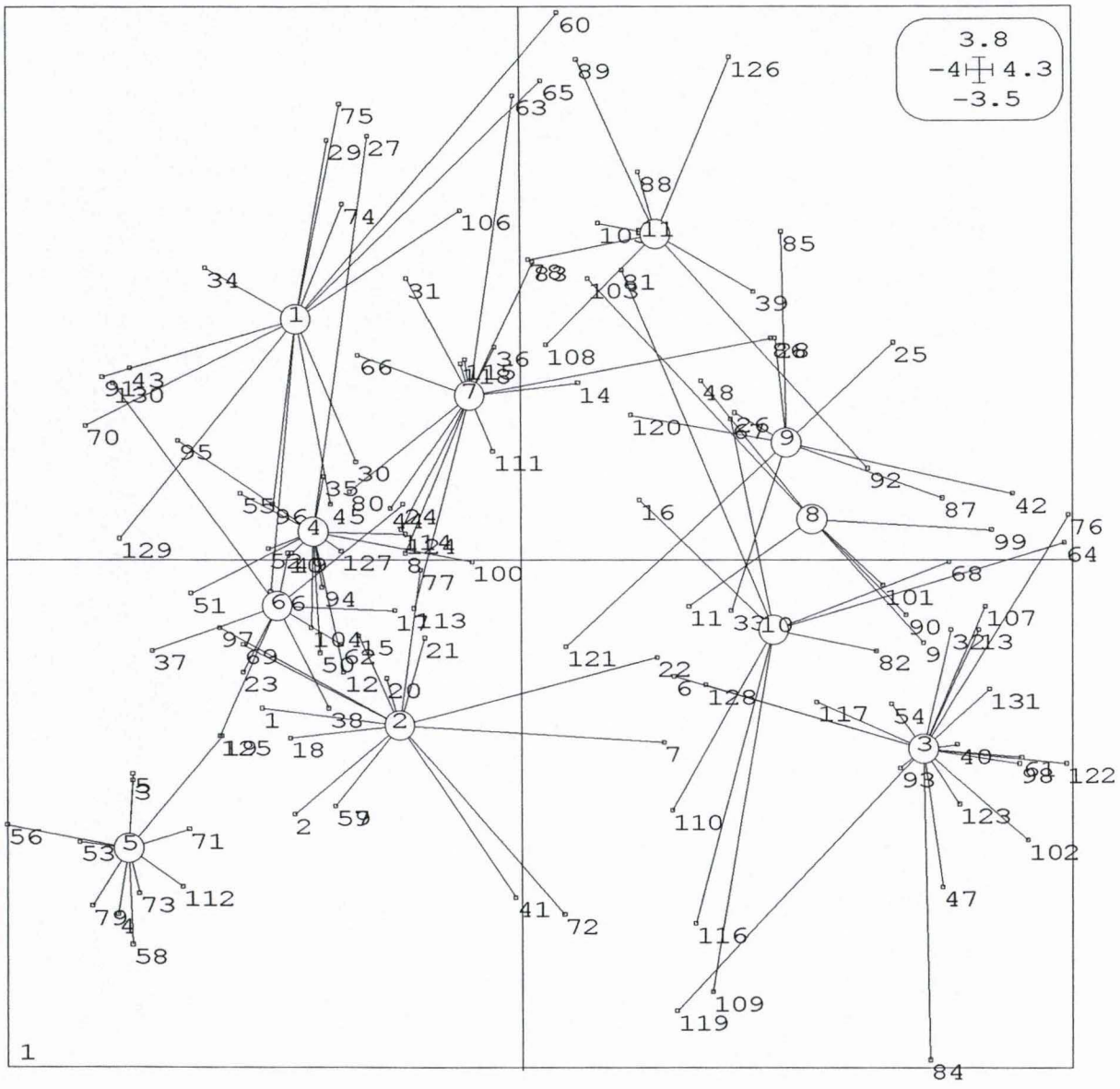
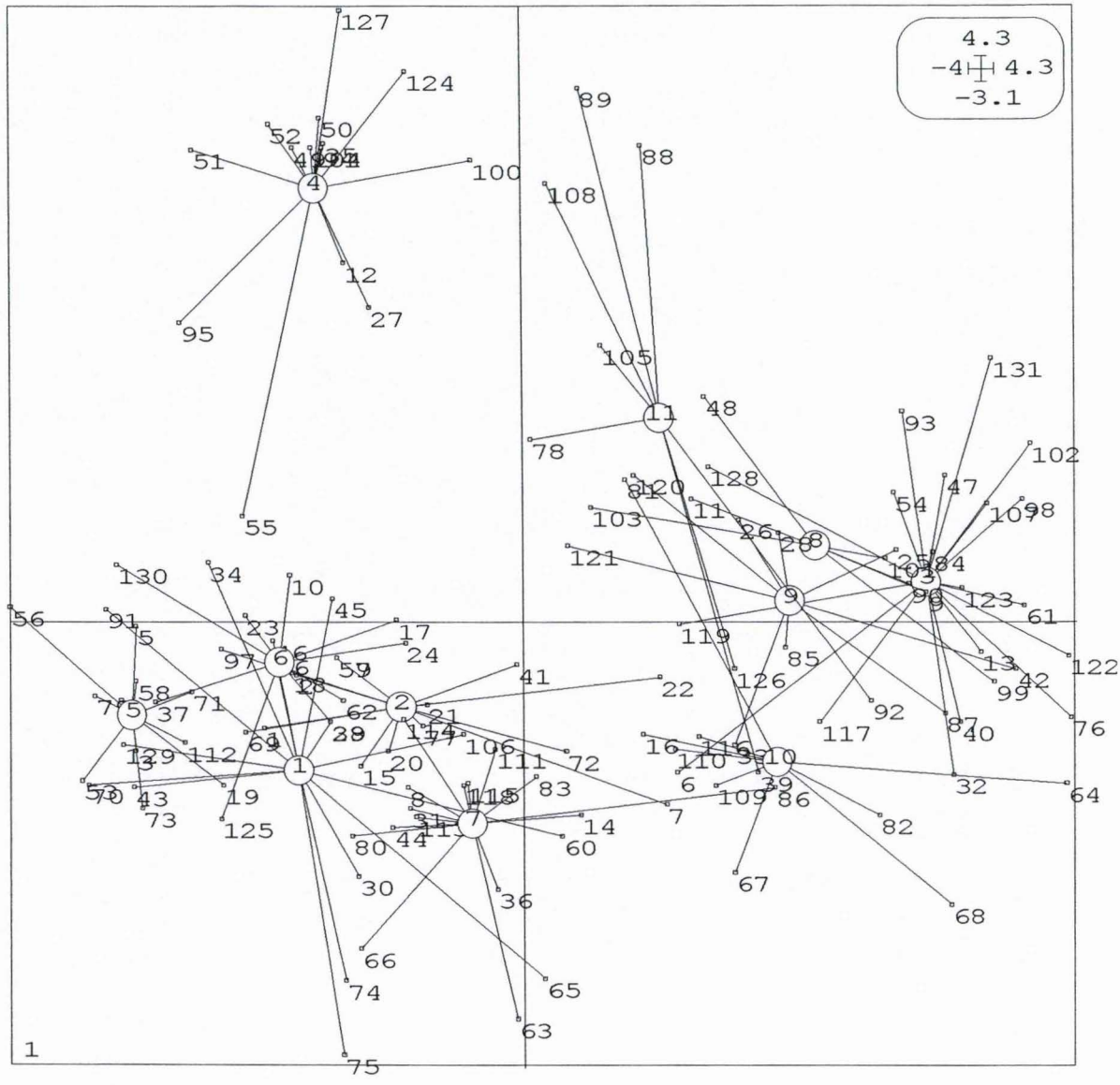


Figure 6 : Axes F1 – F3



3.3 Vegetation Typology

(see annex : phytosociological analysis)

Each record is then assigned to a class defined by a particular floristic composition with characteristic species (discriminating), which are not necessarily the dominating species when these are present in many different formations. For example, *Colophospermum mopane* largely dominates many formations, and only characteristic for the class 7a .

The analysis of the "inertia" of plants for a given class allows to identify the discriminating plants that will be used to characterise classes. These classes will be described in the following paragraphs.

3.3.1 Old fallows and thicket on sandy soil : Class 1a

Records 29, 30, 34, 114, 123, 129 , 133, 134, C2, C7, C8, C18, C46

Medium to dense cover (30 à 60 %) with the following characteristic plants

Acacia nilotica , Acacia nigrescens, Acacia tortilis

26	Combretum elaeagnoides	12[2]
32	Combretum mossambicensis	12
48	Grewia bicolor	10
41	Diospyros quiloensis	5
39	Dichostachys cinerea	4

The herbaceous cover is relatively present 50 to 100 % of the ground and secondarily characterised by :

122	Panicum maximum	3
99	Digitaria milanjiana	2

3.3.2 Fallows on alluvium : Class 1 b

R1, 2, 95 a, 96 , 97,

Variable ligneous cover but always sparse (covering 5 to 15%)

With characteristic plants identical to class 1a, forming facies at :

26	Combretum elaeagnoides	12
32	Combretum mossambicensis	12
85	Ziziphus mauritiana	

And for the herbaceous stratum:

121	Ocimum americanum
135	Trichodesma zeylanicum

[2] an indicator of the contribution of the specie to the characterisation of the class (inertia)

3.3.3. Unclassified vegetation records : Class 2

R15, 18 ,20, 21, 22, 128, 136

Incomplete records, either because of unavailable data on the herbaceous stratum (observations in the dry season) or because of a hybrid facies between two formations (no plant has positive inertia).

3.3.4 Mixed mopane shrubland on shallow soil : Classes 3, 8, 9

These vegetation formations, in which *Colosphospermum mopane* is omnipresent and often associated with *Combretum apiculeatum* differ very little weath eachether. They have an open ligneous cover (5 à 20 %), locally denser in certain records of class 9.

Class 3 : R 6, 7, 13, 32, 40, 42, 98, 106, 118, 135, C4, C9, C13, C 19, C30, C32, C36, C45, C49, C54

Class 8 : R9, 11, 99, C1, C10, C12, C14

Class 9 : R 25, 26, 28, 33, C34 , C35, C55, C57

Tableau 5 : Characteristic species of classes 3, 8 and 9

Class 3		Class 8		Class 9	
Diospyros kirkii	13	Diospyros kirkii	8	Diospyros kirkii	1
Terminalia stenostachya	8	Terminalia brachystemma	7	Combretum apiculatum	2
Terminalia brachystemma	6	Combretum apiculatum	4		
Andropogon gayanus	8	Andropogon gayanus	10	Andropogon gayanus	10
Heteropogon contortus	12	Heteropogon contortus	13	Heteropogon contortus	13
Loudetia flavida	9	Loudetia flavida	5	Digitaria milanjiana	17
Schmidtia pappophoroides	11	Schmidtia pappophoroides	34	Loudetia flavida	1
				Schmidtia pappophoroides	5

3.3.5 Jesse and Gonono bush on sandy soil : Class 4

Relatively dense thickets (40 à 80 % of ligneous cover) associated with the sandy soils of the Gonono crescent.

R 12, 27, 35, 100, 101, 102, 103, 107, C5, C6, C11, C15, C38, C44

Table 6 : Characteristic species of class 4

Class 4	
Baphiamassaiensis	21
Terminalia brachystemma	12
Schrebera trichoclada	4
Combretum elaeagnoides	2
Kirkia acuminata	2
Acacia erioptera	2
Digitaria milanjiana	3
Panicum maximum	2

3.3.6 Dry forest on sandy and shallow gritty soils : Class 5

Very dense vegetation formation with a ligneous cover 60 and 90 % and sparse or inexisting herbaceous stratum.

R3 , 4 , 5 , 19 , 105 , 109, 111, 130, 132, C24

Table 7 : Characteristic species of class 5

Class 5	
Xylia torreana	28
Diospyros quiloensis	14
Meiostemon tetrandrus	8
Pterocarpus lucens subsp. antunesii	2

3.3.7 Thickets and Riparian forests : Class 6

Very dense thickets and riparian formations (covering 70 à 100 %)

R10, 17, 23, 24 , 37, 38, 119, C42

Table 8 : Characteristic species of Class 6

Class 6	
Kirkia acuminata	12
Sterculia africana	4
Acacia nigrescens	3
Acacia ataxacantha	3

3.3.8 Tall mopane woodland : Class 7a

The factorial analysis grouped into a same formation the landscapes of "tall mopanes" and those where the mopanes are more shrubby. These classes are floristically similar but are structurally different. Class 7 will therefore be separated into two sub-classes, 7a for the group "Tall mopane woodland" and 7 b for "mixed mopane woodland"

Class 7a is therefore an open formation with a tall ligneous stratum that covers 25 to 40 % of the ground. It is principally dominated by *Colophospermum mopane* but with a well represented herbaceous stratum, composed mainly of annual plants..

R8, 14, 31, 95 b, 120, 125.

Table 9 : Characteristic species of Class 7a

Class 7a	
Colophospermum mopane	33
Combretum elaeagnoides	
Combretum apiculatum	
Aristida spp	

3.3.9 Mixed mopane shrubbed woodland : Class 7b

In this sub-class, structure is less homogenous and varies between shrubland and woodland with a cover identical to the one of sub-class 7a. However, this formation often appears in a mosaic with the mixed Miombo formation on the sub-outcropping sandstones of Ward 2 (Class 10).

C23, C25, C26, C27, C31, C50, C53, C56

Table 10 : Characteristic species of Class 7b

Class 7b	
Colophospermum mopane	33
Combretum apiculatum	-
Ximenia americana	-
Aristida adscensionis	7
Chloris virgata	5

3.3.10 Mixed miombo – mopane woodland : Class 10

Open formation (ligneous cover of 20 à 30 %) of outcropping sandstones of the west of the study area (forest sandstone), locally denser. Outside the outcrops, the herbaceous stratum is dense with a cover of 80 to 90 %.

R16, 121, 126, 127, 131, C21, C22, C28, C51, C52

Table 11 : Characteristic species of Class 10

Class 10	
Julbernardia globiflora	10
Pseudolachnostylis maprouneifolia	10
Catunaregam spinosa	10
Crossopteryx febrifuga	7
Erythroxylum zambesiacum	4
Dalbergia spp.	4
Colophospermum mopane	-
Heteropogon contortus	5
Pogonarthria squarrosa	13

3.3.11 Dense mixed mopane woodland : Class 11

Dense formation with a ligneous cover 50 and 70 % (locally open) on sandy soils of Gonono crescent .

R39, 137 , C3, C20, C43, C58, C59

Table 12 : Characteristic species of Class 11

Class 11	
Combretum apiculatum	17
Colophospermum mopane	11
Combretum mossambicensis	3
Terminalia brachystemma	3
Digitaria milanjiana	11
Duosperma crenatum	10
Heteropogon melanocarpus	5
Schmidtia pappophoroides	5

4. Mapping methodology

The mapping method is composed of three parts (fig. 8) :

- The study of vegetation, to establish the mapping units (cf. section 3)
- GIS data analysis to overlay ancillary information with Remote Sensing data
- Remote Sensing Image Processing and mapping

4.1 GIS data analysis

The GIS applications and the image processing are related because the SPOT image is used as a map background for the display of the thematic data (soils, geology, geomorphology) as well as the topographic data (hydrology, planimetry et and administrative boundaries). The whole of the thematic data was used in the stratification of the landscape units which will be used in the class aggregation phase.

The very diverse origin of the edaphic maps (often very schematic) make their direct use impossible. It was necessary to re-draw them in order to make them coherent with the SPOT data accuracy. A synthesis geomorphological and landscapes map was elaborated, resulting in the following units:

- Old alluvium formations of the principal valleys
- Recent alluvium
- Gonono crop area
- Dande sandstone
- Zambesian escarpment
- Mixed sandy and gritty soils
- Old fallows
- Folded of Upper Karoo sandstone
- Sandy soils of Gonono crescent (Jesse sand)
- Mixed Dande sandstone and alluvium

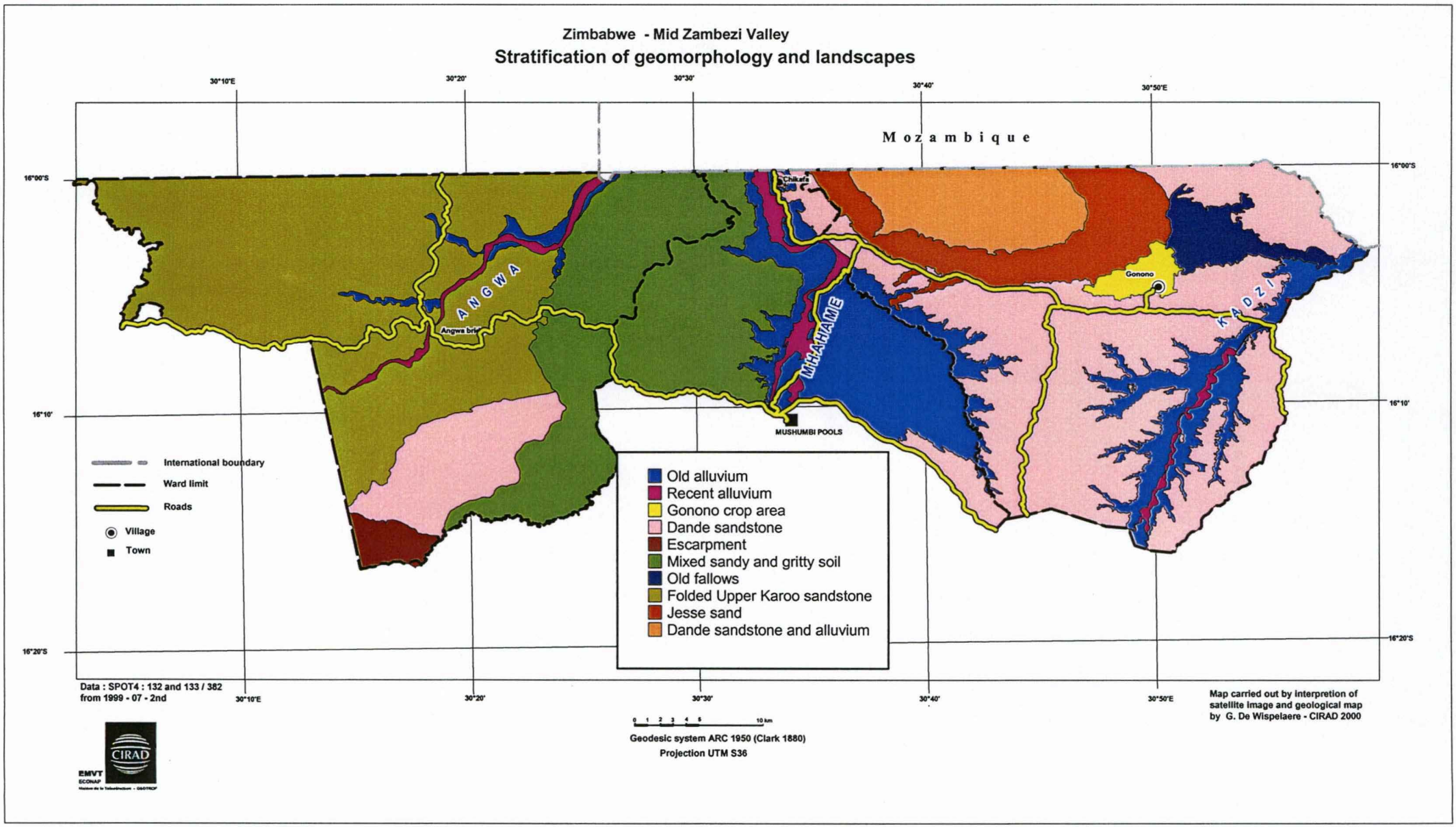
4.2 Image processing and data analysis

The steps of the image processing are presented in the flow chart of figure 7.

4.2.1 Image pre-processing

The two series of digital images was geometrically rectified and geocoded using an orbit correction followed by an adjustment on Ground Control Points (GCPs). The images were then assembled into a mosaic, applying a radiometric equalisation on the overlapping portions. The study zone was then extracted from the mosaic. A colour composite was elaborated using bands Xs3, Xs4, Xs2, applying a gaussian dynamic contrast stretch. On the spatial-map (annex) shows a simplified cartographic display (main roads, administrative boundaries) as well as the location of the vegetation records collected by the different teams.

Figure 7 : Stratification of geomorphology and landscapes



4.2.2 Specific processing

In a first phase of this project (De Wispelaere, 1999) , a supervised classification algorithm was applied to the 1995 SPOT data was, using, as training areas, plots that were chosen within the vegetation records. (Draft map 1 of vegetation cover ; May 1999). During field validation, these preliminary results were found to be locally erroneous and incomplete. Because of the diversity of the ecological systems present in the area, it was necessary to complete surveys, to integrate all available data and to conduct a semi-automatic classification with a strong thematic assistance.

In 1999, we were able to acquire a new SPOT coverage over the study area. These images of SPOT4 have four bands instead of three. The mid-infrared band, Xs4, associated with the Near infrared band, improves the differentiation of vegetation, especially in the dense formations more or less wet.
This series then became the reference image for the vegetation map. The four channels are used as primary data for the non-supervised classification (Baysian classification) in 32 classes, a technique that determines typical sets of pixels in function of their reflectance in the different spectral bands.

CAPI (Computer Assisted Photo-interpretation) applications in the GIS allow to define masks corresponding to thematically coherent groups of pixels (generally corresponding to landscape and geomorphological types).

For each mask we then aggregate the corresponding classes in function of the floristic and structural information issue from the field surveys. These new aggregated classes produce the final cartographic units of vegetation and actually do correspond to a synthesis of vegetation species, structure and geomorphology.

4.3 Vegetation cover map units

The relationship between a vegetation class obtained through the phyto-sociological and structural analysis and the spectral response in the satellite image are ambiguous . In deed, different vegetation formations can have similar spectral responses and different spectral responses can correspond to the same vegetation formation but having different vegetative coverage, either at the level of the ligneous stratum or the herbaceous stratum. These limitations increase with the desired precision. The map legend is a complex synthesis between the structural aspects of vegetation, the discriminating floristic species identified in the factorial analysis and the underlying morpho-pedological conditions.

Some of the components of the landscape are not related to spontaneous vegetation, for example cultivated, burned or eroded land, mineral outcrops (alluvial or rock), water bodies, urban areas. In addition to clouds and cloud shadows, which are impossible to eliminate, all these elements are present in the image.

Figure 8 : Methodology

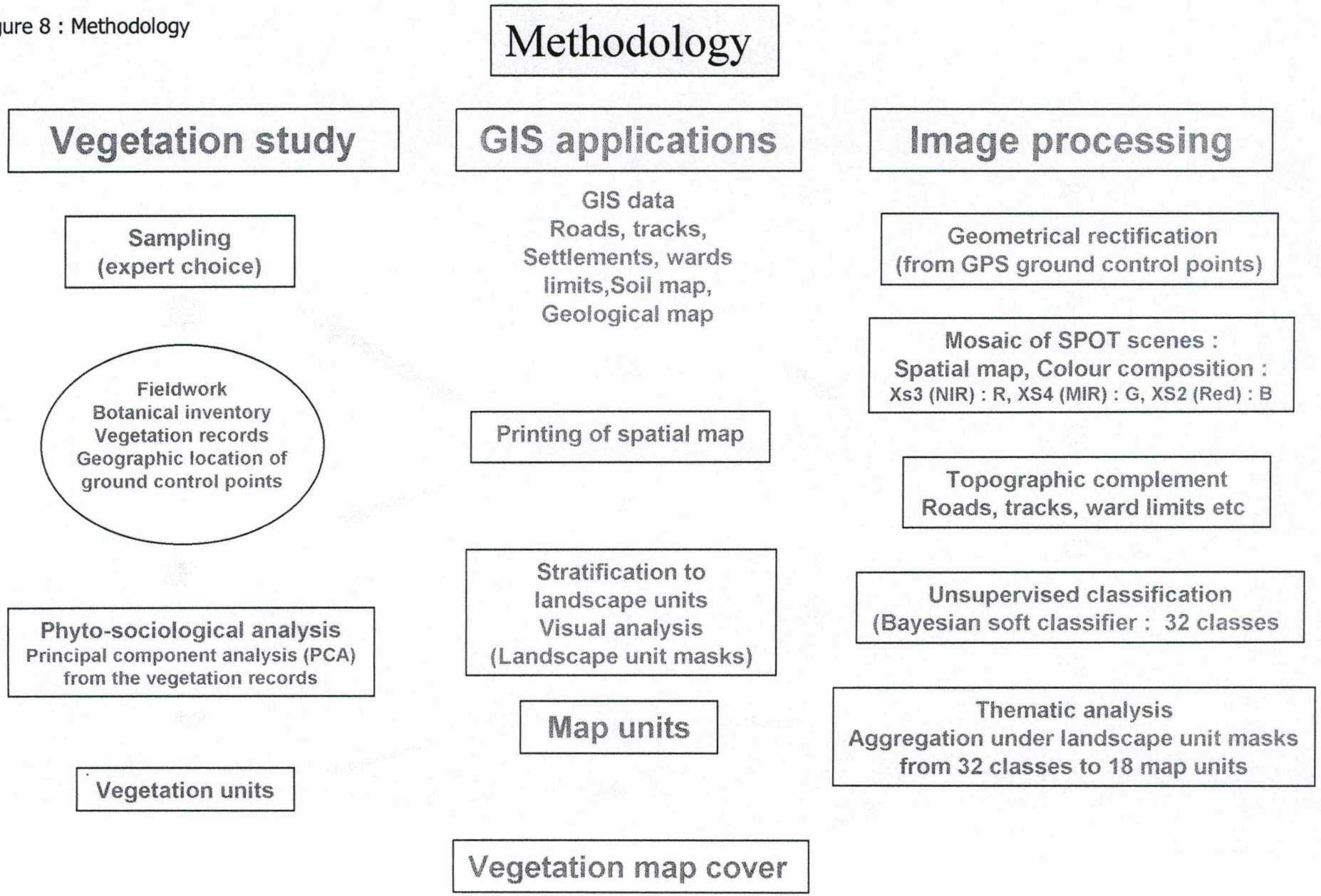


Table 7 : Legend of the vegetation cover map

1 **Pools**
2 **River deposit**
3 **Miscellaneous (cloud shadows, recent burned areas, hillside shadows)**
4 **Crops and fallow on actual alluvium (associated with grassland)**
5 **Crops and fallow on old alluvium**
6 **Crops and fallow on various soils**
7 **Settlements and bare soils**
8 **Riparian forests and thickets on alluvium and in gullies (vegetation unit 6)**
9 **Grassland on alluvium or pan**
10 **Dry forest on sandy and gritty soils** with *Xylia torreana, Diospyros quiloensis,* and *Pterocarpus lucens subsp. antunesii* **(vegetation unit 5)**

11 **Jesse and Gonono bush on sandy soils** with *Baphia massaiensis, Terminalia brachystemma, Digitaria milanjiana, Panicum maximum* **(vegetation unit 4)**

12 **Old fallows, thickets on sandy soil** with *Acacia nilotica, Acacia nigrescens, Acacia tortilis, Combretum apiculatum, Combretum mossambicensis, Grewia bicolor, Digitaria milanjiana* **(vegetation unit 1a)**

13 **Dense mixed mopane woodland on sandy soil** with *Combretum apiculatum, Colophospermum mopane and Digitaria milanjiana, Duosperma crenatum* (vegetation unit 11)

14 **Tall mopane woodland** with *Colophospermum mopane, Combretum elaeagnoides, Combretum apiculatum and Aristida spp* **(vegetation unit 7a)**

15 **Mixed mopane shrubland on shallow soil** with *Diospyros kirkii, Terminalia brachystemma, Combretum apiculatum and Schmidtia pappophoroides, Andropogon gayanus, Heteropogon contortus* **(vegetation units 3, 8, 9)**

16 **Mosaic of miombo - mopane woodland and mopane shrubbed woodland** with *Julbernardia globiflora, Pseudolachnostylis maprouneifolia, Catunaregam spinosa, Crossopteryx febrifuga, Diospyros kirkii, C* and *Pogonarthria squarrosa, Heteropogon contortus* **(vegetation units 10)**

17 **Sparse vegetation on sandstone outcrops** with *Colophospermum mopane, Combretum apiculatum, Maerua edulis* **(vegetation unit 7b)**

18 **Escarpment shrubland** with *Brachystegia allenii, Julbernardia globiflora, Loudetia flavida, Heteropogon contortus* (no vegetation records)

19 **Escarpment woodland in gullies** with *Brachystegia allenii* (no vegetation records)

5. Conclusions

The vegetation of this part of the Mid Zambezi valley presents remarkable floristic richness with a diversity of landscapes related to the general soil groups easily visible on the high resolution satellite images.

The method used for the vegetation cover mapping is original because of the use of a statistical phyto-sociological analysis procedure to define vegetation classes. These vegetation classes do not appear directly on the images, these informing more about the structure of the vegetation cover than about the nature of the species that compose it. It is therefore necessary to define cartographic units through a thematic interpretation of the vegetation classes, considering their structure and geomorphology, in function of their spectral characteristics in the images. These units are a compromise between the level of knowledge that we would like to map and the potential of the satellite imagery.

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ANNEX 1

(Example of a vegetation record form)

Vegetation survey form[3]			
Site n°: **04**	Region : Ward 3	GPS location	
Date : 08-04-99	Locality: Mavura	Lat (°) or Y (m)	Long (°) or X(m)
Time 11 h		8 224195	226847
Observer : PP/DD/GDW	Field photo :		
Map reference, Datum, projection ARC50 –S.UTM36			

Landform and site description

Thalweg	M. water channel	Flood pl.	Bank	Valley	Plain	Plateau	Footslope	Midslope
					X			
Upperslope	Hill crest	Pan	Dune	Other :				

Soil surface and soil type

Rock outcrop (> 60 cm)	Stones (6-60 cm)	Pebbles (2-6 cm)	Gravel 0.2-2 cm)	Soil (< 0.2 cm)	Org. litter
Clay	Silt	Loam	Sandy loam	Loamy sand	Sand X

Erosion	Low	Medium	High
Gully			
Rill			
Sheet			

Disturbances

Settlement	Cultivation	Clearing	Fire	Termitarium	Other

Vegetation stratification and classification

	Average height (m)	Vegetation cover	Rate
Forb	**0.8**	**Forb density**	**40 %**
Grass	**-**	**Grass density**	**-**
Shrub	**6 m**	**Shrub density**	**80 %**
Tree	**12 m**	**Tree density**	**40 %**

Vegetation class	**Dominant species**
Dry forest	***Xylia torreana , Pterocarpus lucens***

Notes/comments : Dense thicket : Jesse bush

[3] *G. De Wispelaere adapted from J Sweet and A. Burke 1998 NOLIDEP_Namibia*

Record N° 4-99

	Woody Stratum	Height classes							A-D
Col N°	Species composition	3	4	5	6	7	8	9	
	Xylia torreana					5	4		4
793	Pterocarpus lucens subsp. antunesii						5		3
	Baphia massaiensis				2				1
773	Combretum sp.				1				+
774	Hippocratea africana				1				+
	Monodora junodii					7			4
775	Strychnos decussata						3		2
777	Alchornea laxiflora				1				+
778	Elachyptera parvifolia				1		1		+
	Strophanthus kombe						1		+
791	Canthium frangula				1				+
	Acacia ataxacantha	2			1				1
792	Bauhinia tomentosa			1					+
	Cleistochlamys kirkii					1			+
794	Pteleopsis myrtifolia				1				+
	Balanites maughamii				1				+
796	Vangueria infausta				1				+
	Diospyros quiloensis				2				1
798	Grewia flavescens			1					+
799	Boscia angustifolia			2	1				+
802	Combretum elaeagnoides				2	1			1
803	Strychnos spinosa				1				+
	Friesodielsia obovata				1				+
805	Xylotheca tettensis				1				+
	Markhamia zanzibarica				1				+
806	Boscia angustifolia				1				+
	Dalbergia martinii				1				+
808	Croton longipedicellatus				1				+
812	Erythrococca menyhartii						1		+
813	Pavetta cataractarum		1	1					+
814	Maerua edulis		1						+
815	Tricalysia junodii	1							+
816	Citropsis daweana			1					+
	Berchemia discolor						3		2
821	Vangueria infausta		1						+
	Elaeodendron schlechterianum *			1					+

Record N° 4-99b

	Herbaceous stratum	Height classes						A-D
Col N°	Species composition	1	2	3	4	5	6	
781	Justicia heterocarpa			1				1
782	Asystagia gangetica				1			+
783	Celosia trigyna				1			+
786	Triumfetta annua				5			3
785	Vernonia anthelmintica				2			1
	Achyranthes aspera			3				2
787	Blainvillea gayana				1			+
	Stylochaeton puberulus			1				+
788	cf. Aneilema nicholsonii			1				+
790	Vigna ungiculata		1					+
795	Blepharis maderaspatensis		1					+
797	Hibiscus lunariifolius			2				1
800	Panicum trichoides			1				+
804	Momordica kirkii	1						+
807	Justicia kirkiana			1				+
809	Desmodium tortuosum			1				+
810	Cissampelos mucronata			1				+
811	Hibiscus lobatus				1			+
818	Pupalia lappacea				2			1
823	Vigna unguiculata		1					+
822	Vigna unguiculata		1					+
824	Macrotyloma daltonii		1					+
825	Pycnostachys stuhlmannii		1					+

ANNEX 2

(Statistics of map units, in ward)

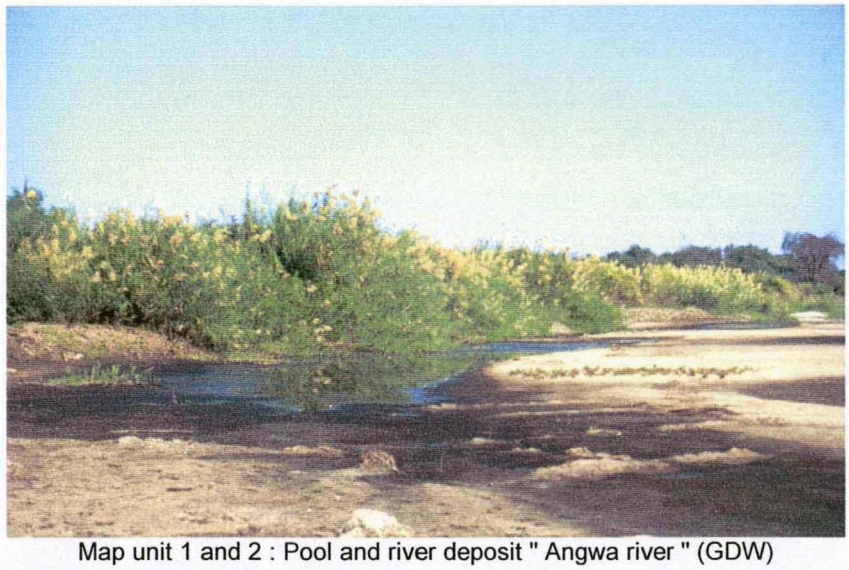
Map units	Units (Ward 2)	Area (ha)	Area %
1	Pools	3181,2	0,37
2	River deposit	5749,6	0,67
3	Miscellaneous	1086,4	0,13
4	Crops and fallow on actual alluvium	2108,4	0,24
5	Crops and fallow on old alluvium	5822	0,68
6	Crops and fallow on various soils	40686,4	4,72
7	Settlements and bare soils	40290,8	4,68
8	Riparian forests and thickets	47533,2	5,52
9	9 Grassland on alluvium or pan	48698,4	5,65
10	Dry forest on sandy and gritty soils	-	-
11	Jesse and Gonono bush on sandy soils	-	-
12	Old fallows, thickets on sandy soil	75100,4	8,72
13	Dense mixed mopane woodland on sandy soil	7080	0,82
14	Tall mopane woodland	121646	14,12
15	Mixed mopane shrubland on shallow soil	344060,4	39,94
16	Mosaic of miombo - mopane woodland and mopane shrubbed woodland	97520,4	11,32
17	Sparse vegetation on sandstone outcrops	10213,6	1,19
18	Escarpment shrubland	8364,8	0,97
19	Escarpment woodland in gullies	2253,2	0,26
		861395,2	**100,00**

Map units	Units (Ward 3)	Area (ha)	Area %
1	Pools	2781,2	0,77
2	River deposit	1277,6	0,35
3	Miscellaneous	45,2	0,01
4	Crops and fallow on actual alluvium	12461,2	3,46
5	Crops and fallow on old alluvium	53204,8	14,78
6	Crops and fallow on various soils	19473,6	5,41
7	Settlements and bare soils	18423,2	5,12
8	Riparian forests and thickets	15782,8	4,38
9	9 Grassland on alluvium or pan	1892,4	0,53
10	Dry forest on sandy and gritty soils	34,4	0,01
11	Jesse and Gonono bush on sandy soils	-	-
12	Old fallows, thickets on sandy soil	87540,4	24,32
13	Dense mixed mopane woodland on sandy soil	64816,8	18,00
14	Tall mopane woodland	79399,6	22,05
15	Mixed mopane shrubland on shallow soil	-	0,00
16	Mosaic of miombo - mopane woodland and mopane shrubbed woodland	158,4	0,04
17	Sparse vegetation on sandstone outcrops	-	-
18	Escarpment shrubland	-	-
19	Escarpment woodland in gullies	2716	0,75
		360007,6	**100,00**

Map units	Units (Ward 4)	Area (ha)	Area %
1	Pools	696	0,09
2	River deposit	3650,8	0,45
3	Miscellaneous	6306,8	0,77
4	Crops and fallow on actual alluvium	46	0,01
5	Crops and fallow on old alluvium	18411,6	2,26
6	Crops and fallow on various soils	15142,8	1,86
7	Settlements and bare soils	21804,8	2,67
8	Riparian forests and thickets	11358,4	1,39
9	9 Grassland on alluvium or pan	7340	0,90
10	Dry forest on sandy and gritty soils	90692	11,12
11	Jesse and Gonono bush on sandy soils	28916,4	3,54
12	Old fallows, thickets on sandy soil	20052,4	2,46
13	Dense mixed mopane woodland on sandy soil	244204	29,93
14	Tall mopane woodland	344756,8	42,26
15	Mixed mopane shrubland on shallow soil	63,6	0,01
16	Mosaic of miombo - mopane woodland and mopane shrubbed woodland	84,4	0,01
17	Sparse vegetation on sandstone outcrops	-	-
18	Escarpment shrubland	-	-
19	Escarpment woodland in gullies	2362,4	0,29
Total		**815889,2**	**100,00**

ANNEX 3

(Photos of the main landscapes)



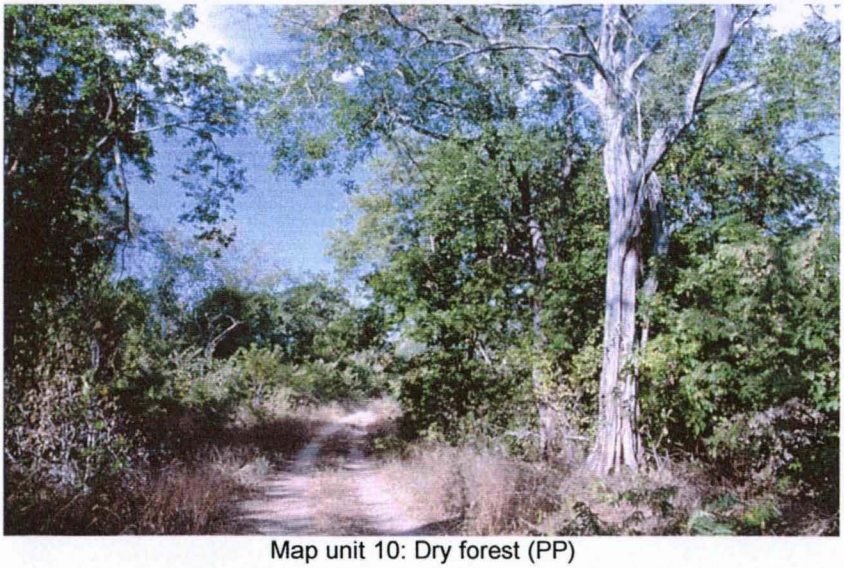
Map unit 1 and 2 : Pool and river deposit " Angwa river " (GDW)

Map unit 3: Bush fire (GDW)

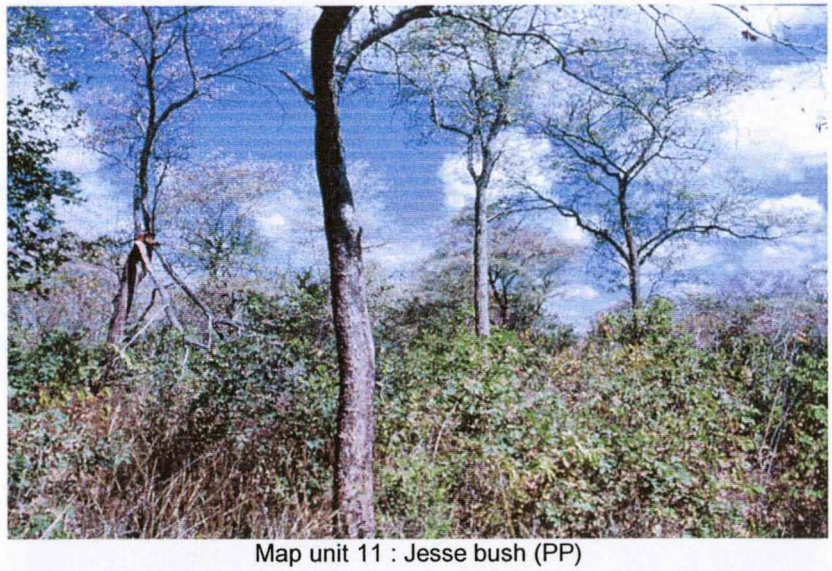
Map unit 4 : Fallow on recent alluvium (GDW)

Map unit 6 : Fallow on various soils (GDW)

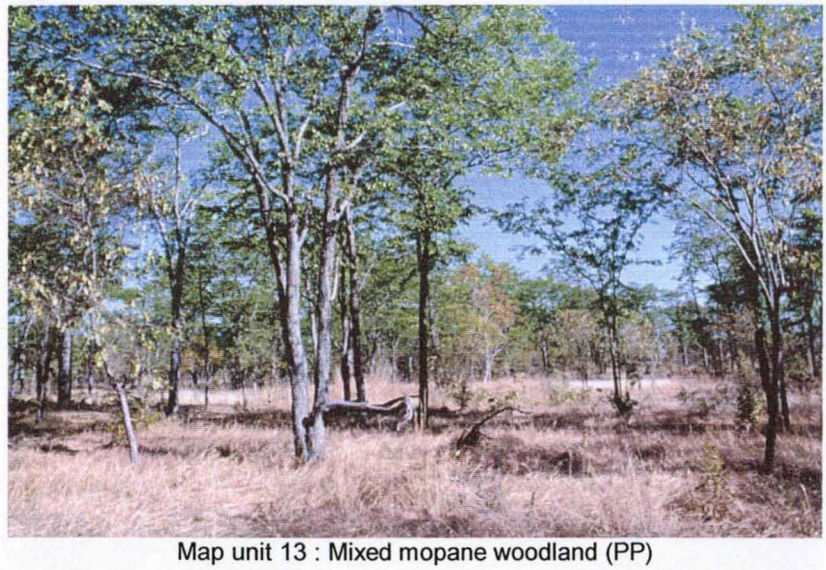
Map unit 8 : Riparain vegetation (PP)



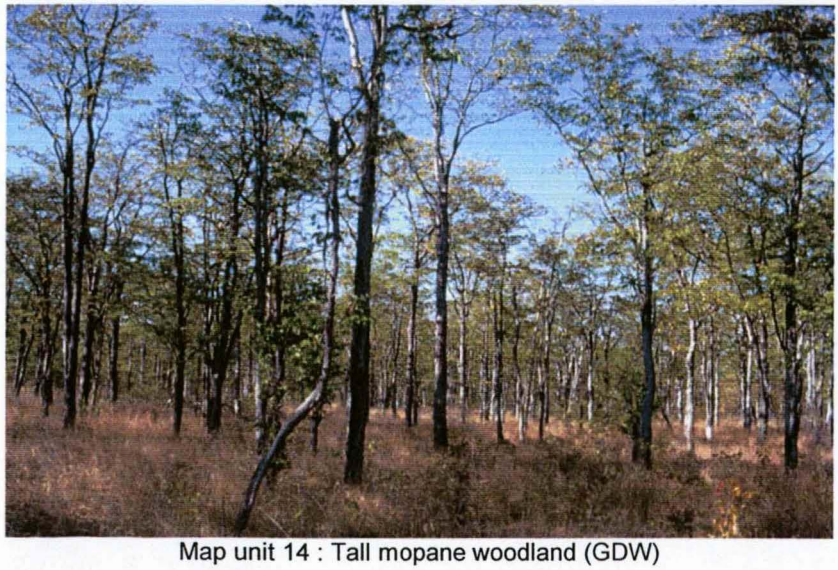
Map unit 10: Dry forest (PP)



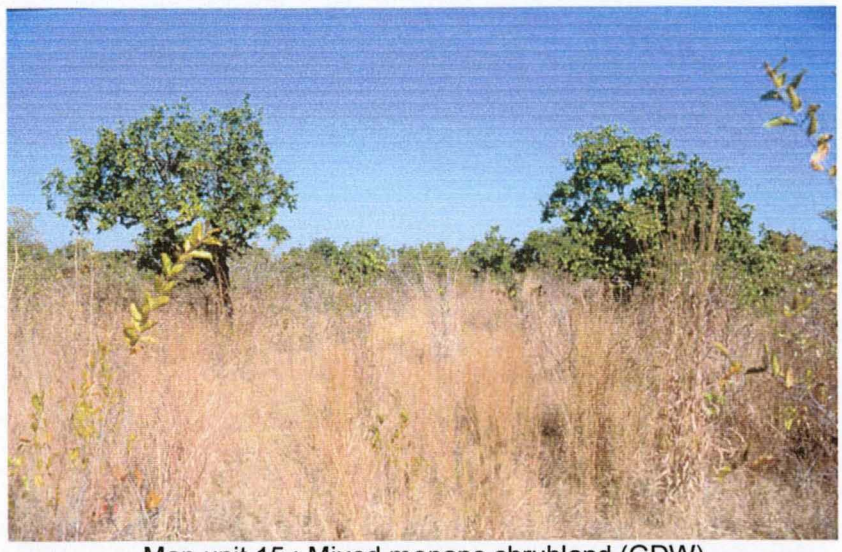
Map unit 11 : Jesse bush (PP)



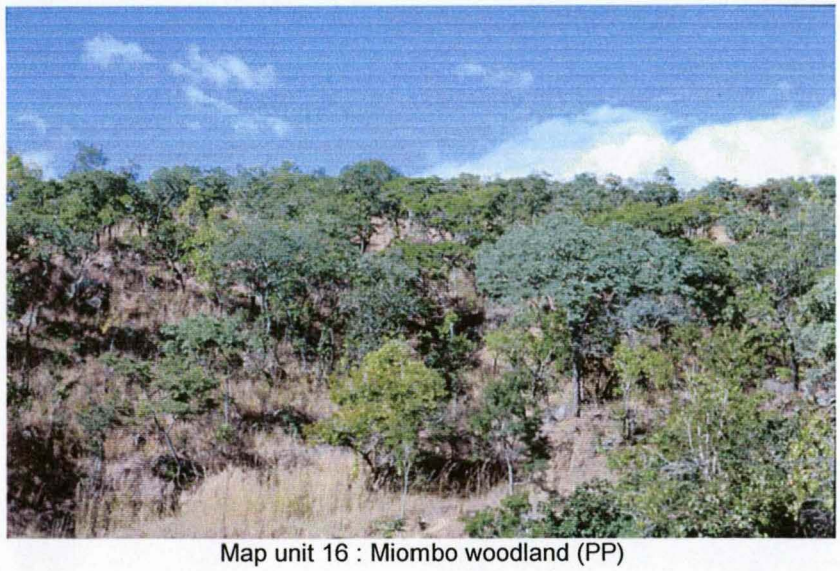
Map unit 13 : Mixed mopane woodland (PP)



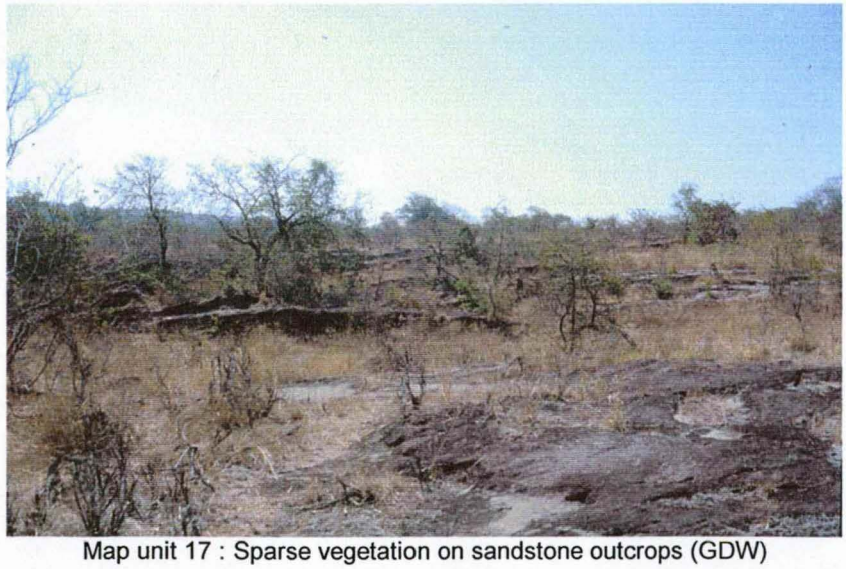
Map unit 14 : Tall mopane woodland (GDW)



Map unit 15 : Mixed mopane shrubland (GDW)



Map unit 16 : Miombo woodland (PP)



Map unit 17 : Sparse vegetation on sandstone outcrops (GDW)