EVALUATION OF LANDSAT MSS DATA FOR TERRAIN ANALYSIS AND RANGELAND MANAGEMENT IN THE LOWER OKAVANGO DELTA REGION, NGAMILAND, BOTSWANA

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ABSTRACT

The thesis examines the value of satellite data for terrain analysis and aspects of rangeland evaluation in Ngamiland, northern Botswana. The study area encompasses the main livestock production zone of the district.

An analysis of terrain was considered integral to detailed analysis and use of satellite data for resource assessment and management. The terrain analysis was based on interpretation of multitemporal Landsat data, and aerial photography, supported by detailed field investigation. A number of classification procedures and computer based digital enhancement techniques were used to facilitate analysis and classification of the data. Terrain types were identified by relating image characteristics to terrain features, primarily vegetation patterns.

Relationships between the Landsat data and various ground features related to rangeland resources were analysed. These were mainly related to vegetation parameters, including cover, structure and species composition. The most important factor investigated, was the relationship between cover values of woody vegetation and the satellite data. The results were used to develop a classification using the Landsat digital data.

The usefulness of Landsat data for rangeland management, and the importance of adequate ground survey and other support data sources, is discussed in the light of results obtained.

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I. Introduction

This thesis examines the use of the Landsat Multispectral Sensor System (MSS) for terrain analysis and rangeland management purposes in the lower Okavango Delta region of Ngamiland, Botswana; an extensive area of semi-arid, natural terrain into which flows the Okavango River, to form a large inland Delta system.

Since the launch of the first Landsat Satellite in 1972, the availability of MSS data has provided opportunities for investigations of extensive areas of natural and semi-natural terrain. Large amounts of data have been acquired during this period; its use for many purposes remains to be explored. Sequential data of the Okavango Delta region has been acquired for 1972, 1973, 1975, 1976 and 1983, providing the opportunity to study the region and to monitor temporal changes in ground features and conditions.

The MSS system records data in a number of carefully selected, discrete parts of the electromagnetic spectrum. The choice of wave bands was based on measurements of the reflectance characteristics of a large number of ground components. The Landsat system was developed as a tool for resource evaluation; particularly for agricultural census and monitoring purposes.

In the study of natural terrain using MSS data, an understanding of the characteristic reflectance responses of the terrain (within the range of the sensor system) is essential for effective, use of the data. In this study particular emphasis was placed on those relationships which could be used for specific rangeland evaluation and management purposes.

To provide an understanding of the value of satellite data for terrain analysis and resource evaluation, the basic concepts and rationale for multispectral data use is described in Chapter II. The Landsat MSS system is detailed, with emphasis on features of relevance to the study of natural terrain. The nature of the MSS data products (both digital and photographic) are described, together with the computer based image processing systems used in the study. The advantages of digital multispectral data compared with other forms of data are evaluated.

To provide the framework for the research, the physical and economic geography of the region comprising the south-eastern part of the Okavango Delta and the Lake Ngami basin, is described (Chapter III). The nature of the terrain presents a number of discrete problems for agricultural use and particularly for livestock production.

Analysis of available Landsat data prior to field survey facilitated the selection of specific areas for ground data collection for detailed evaluation. In the choice of these areas, the availability of other sources of data and opportunities for access within the difficult, remote terrain were important considerations.

During the period of the field study an aerial photographic survey of the delta region, commissioned by the Botswana Government was undertaken. Advantage was taken of the availability of this material.

In the study of the physical geography of the Okavango area attention was focused on those factors which reflect the reflectance characteristics of the natural terrain, and which affect the use and condition of rangeland resources. These considerations are often interrelated; for example, fluctuations in annual rainfall can affect vegetation cover, soil moisture conditions and distribution of surface water, which will affect both reflectance characteristics of the terrain, and the condition and use of rangeland.

Because of the nature of the physical environment, the main economic activity is cattle rearing, utilizing common grazing land. Some arable agriculture is undertaken for subsistence. Livestock production (including localised small stock; sheep and goats) is considered within the context of its interaction with the natural environment.

The use of Landsat MSS data for terrain analysis is evaluated in Chapter IV. Terrain analysis and classification using multispectral data is compared with conventional methods, and indices of environmental conditions (used in classification) are examined. A method of analysis using the MSS data is described, and the applicability of vegetation as an index of environmental conditions is evaluated. Methods used to handle the digital data and the advantages and disadvantages associated with visual and computer-based classification procedures are assessed.

The terrain classification was regarded as essential for providing a framework for further detailed study, using Landsat MSS data; in particular, the use of MSS data as a tool for rangeland survey within the Okavango region.

The role of MSS data in providing specific information of value for rangeland management is evaluated in Chapter V. The particular relationships examined are those between the woody plant component of rangeland vegetation and the reflectance characteristics of the terrain. The importance of woody vegetation within areas of rangeland is described. The extent to which it was possible to develop an accurate method of mapping spatial variation in cover of woody vegetation (based on relationships between cover and the reflectance data) is examined. The technique developed to map woody cover is described in detail. Other relationships, such as those between physiognomy, structure and species composition of woody vegetation and their affect on reflectance characteristics of the terrain being studied, were considered. The role of physiognomic differences of woody vegetation on reflectance responses is examined in more detail in Chapter VI. Physiognomic differences in vegetation dominated by woody plants were present throughout the study area, in some instances within areas dominated by a single species. This occurs in the case of two particular woody species, Colophospermum mopane and Terminalia sericea. C. mopane also has a tendency to form a mosaic of open woodland and shrub savanna, with distinct boundaries between the two physiognomic types. An area of C. mopane mosaic was selected for the purposes of studying the affects of these differing growth forms on reflectance responses. The method and results of the analysis are described, and the role of physiognomy examined. Some suggestions as to the formation and maintenance of the C. mopane mosaic are also considered.

The results of the study are evaluated in the final chapter and some recommendations are provided on the use of satellite technology for terrain and resource surveys, with particular emphasis on its application in developing countries.

II. Basic Considerations Concerning Landsat Multispectral Sensor Data.

2.1 The concept and rationale of multispectral remote sensing.

"All objects within a natural landscape absorb, transmit, reflect, and emit radiation selectively." (Polcyn et al., 1969). Different objects vary in their response to electromagnetic energy at any particular wavelength, and an individual object will vary in its response in different parts of the electromagnetic spectrum. For example, solar radiation incident on a healthy green leaf, will be highly absorbed in the visible red part of the spectrum (wavelengths around 0.65 μm), and highly reflected in the infra-red (0.72 to 1.3 μm) (fig. 2.1). These differences are controlled by a number of factors, including pigmentation and cell structure.

The concept of multispectral remote sensing is based on variations in response to the electromagnetic spectrum, which can be used to aid in the identification of objects or ground features (Rehder, 1978). The characteristic behaviour of an object at any given wavelength is known as its ´spectral response´. A ´spectral response curve´ for an idealised, green leaf surface is shown in figure 2.1.

Given that individual objects possess characteristic response curves, these objects may be distinguished from one another on the basis of their reflectance levels in different parts of the spectrum. A multispectral sensor system usually divides the spectrum into discreet units, the sensor recording

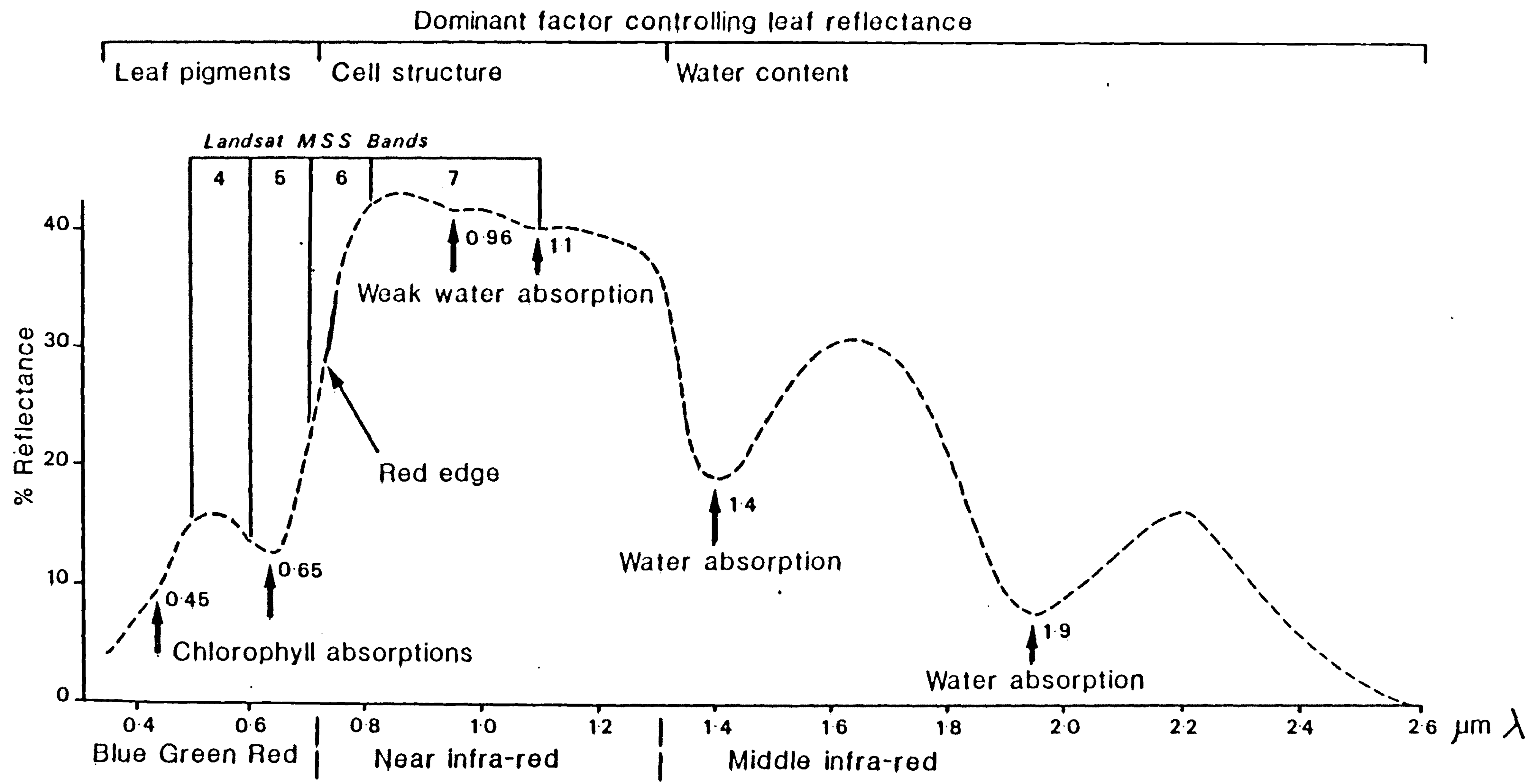


Fig. 2.1 Typical 'green leaf' spectral response curve.

the reflectance (or emittance) level of an object between selected wavelength ranges. Certain systems use an array of cameras and photographic film, which is sensitive to small ranges of the spectrum. Other advanced systems use an optical-mechanical scanner to record the radiant energy level of the objects. This data is usually converted into digital form, to be transmitted to a ground station, or recorded on magnetic tape. This is done for a number of units or wave-bands of the electromagnetic spectrum, for example the Landsat multispectral sensor (MSS) records the reflectance levels of ground features at four discreet sets or 'bands' of wavelengths.

Multispectral remote sensing provides advantages for interpretation over conventional aerial photography, which is confined to one or more relatively broad spectral ranges. The distinct differences between objects at particular wavelengths, are often obscured by a large range. The selection of specific discreet ranges for particular tasks is not possible with conventional black and white, 'true' colour or colour infra-red films.

Interpretation of ground conditions, may involve single or multiple band combinations of the data. Recorded reflectance or emittance levels are usually displayed for interpretation as either single band, black and white images, or as multiple band, colour coded images (see section 2.4.2). Interpretation of the resultant image is based on the tonal or colour variations between objects, referred to as the 'contrast'. The relative magnitude of the variation is termed the 'contrast ratio'. For example, black asphalt typically reflects about two percent of solar energy incident upon its surface, while white snow reflects about eighty percent, the contrast ratio between these features is high. However, timberland reflects only three percent of the incident radiation, resulting in a low contrast ratio with asphalt. The higher the ratio, the greater the contrast and the easier it is to distinguish between features. Interpretation is not totally based on the contrast in spectral responses, but also on texture, shape and size of various features (Rehder, 1978). However, it is the spectral response (tone or colour) between a ground feature and those surrounding it, which allows a determination of the size and shape (spatial characteristics) of the feature (Hoffer, 1978).

Discreet parts of the spectrum can be used to achieve particular tasks. The visible red wavelengths provide sharp contrasts between vegetation and cleared or bare ground (Rehder, 1978). The visible blue-green wavelengths provide useful data on shallow or sediment laden bodies of water. Combinations of these discreet bands often provide greater information than single bands. The combination of red and near infra-red wavelength data, has proved useful in vegetation studies (Curran, 1980; Miller and George, 1980; Griffiths and Collins, 1983).

Multispectral data has been collected both photographically, and in digital form. Both approaches are far more flexible than simple monochrome or colour photography in terms of data analysis, however, digital data allows greater flexibility still. Digital data is suitable for computer enhancement and for quantitative analysis and classification.

2.2 The Landsat Multispectral Sensor System (MSS).

2.2.1 Landsat satellite.

The Landsat system has been in operation since 1972. Four, of the series of satellites, were in operation during part of the period 1972 to 1983, which covers the Landsat data used in the present study.

The orbital altitude of the Landsat system is approximately 900 kilometres above the earth's surface. It orbits on a near polar, sun-synchronous path, passing the same position, on the earth's surface, once every 18 days (or 252 orbits) (Richardson, 1978).

The system collects data along a path or 'swath', approximately 185 kilometres wide. The MSS system records levels of reflected solar radiation from the earth's surface. It collects energy levels from four distinct sections (or 'bands') of the electromagnetic spectrum. The reflected radiation hits a rapidly oscillating mirror, which focuses the radiation onto an array of sensors which record the energy values and convert them to a digital format. The instantaneous field of view of each sensor, of the ground surface, is 79 m x 79 m. Signal conversion to digital format results in a 56 m. nominal spacing between readings, in the direction of scan (perpendicular to the line of flight). Therefore, recorded 'image' values form a matrix of 56 m x 79 m cells, while the energy values measured are derived from the full 79 m x 79 m ground resolution square (Lillesand and Kiefer, 1979). The square is the basic unit of measurement, the value recorded is the average reflectance for that square, within a particular wave band. The square is usually known as a 'picture element' or 'pixel'.

There are nominally 3240 pixels across the swath width (forming one scan line), with a range between about 3000 and 3450 pixels. An MSS scene is usually formed of about 2340 scan lines. This gives a nominal pixel count of 7,581,600 per MSS band.

The ground area covered by a single scene is approximately 185 km x 185 km.

2.2.2 Landsat MSS bands.

The MSS system records reflectance values in four discreet wave bands (fig. 2.1). These are numbered Bands 4 to 7 (the first three of the systems channels are allocated to a return beam vidicon system (RBV)).

MSS band 4 (green, 0.5 to 0.6 µm.). This band includes the low green peak of vegetation reflectance (0.54 µm.). Definition of ground features in this band is generally poorer than in the other three bands. This is due to atmospheric scattering and absorption.

MSS band 5 (red, 0.6 to 0.7 µm.). Low vegetation reflectances, related to high chlorophyll absorption, are recorded in this band at 0.65 µm. MSS band 5 provides the best general discrimination over a wide range of surface conditions. It is often chosen if only a single band is to be acquired.

MSS band 6 (red to near infra-red, 0.7 to 0.8 µm.). This band includes the region of greatest increase from low visible to high near infra-red vegetation reflectance (the 'red edge'). The band is often omitted from composite images because the red edge effect can make interpretation difficult.

MSS band 7 (near infra-red, 0.8 to 1.1 µm.). Maximum haze penetration is achieved with this band. MSS band 7 often has the highest reflectance values of the four MSS bands. High reflectance from vegetation is a feature of the near infra-red region (0.72 to 1.3 µm.), and MSS band 7 (Hoffer and Johannsen, 1969). This is due to the cellular structure of leaves, which scatter energy in the near infra-red range.

Radiance values for individual pixels range between 0 and 255, or 0 and 63 (depending on the data source). Zero represents very low reflectances and 255 (or 63), represents very high reflectances. The system was designed to collect data in a variety of illumination conditions, from low light conditions in polar regions, to bright desert areas (Lillesand and Kiefer, 1979). Thus, pixel values in most Landsat scenes occupy only a small range of the possible values.

2.2.3 Landsat data products.

Landsat data is transmitted to ground receiving stations as the satellite comes within range during its orbits. If the satellite is in range, it can collect and transmit data in real time. When out of range, the system's on board tape recorders are used to store data. Storage space is limited and this has resulted in sparse Landsat coverage of certain parts of the world.

The digital data is processed by the ground stations and copied to computer compatible tape (CCT) for general usage. A number of different formats are produced, depending on the the source. For example, the EROS data centre, in the United States, produces tapes with 2340 scan lines per scene, while the Fucino receiving station (Italy), produces tapes with 2286 lines (Nigel Press Associates, 1983). The image data set is regarded as a matrix of scan lines (rows), and columns, for digital processing. Individual pixels can be located using the matrix as a coordinate grid.

Both CCT's and basic film products ('bulk processed' images), are available of Landsat MSS data. Digital data (CCT's) are preferred for detailed analysis, because the bulk processing of film products does not allow for the full dynamic range of the original data to be reproduced. High spatial resolution is also lost. Various soft-ware packages and image analysis systems have been developed to deal with Landsat digital data. Computer processing of Landsat data provides consistent and automated, enhancement, correction and classification facilities.

2.3 Digital Image Processing Systems.

Several systems were used during the period of the present study. A library of image processing programs was available at Bedford College (Chandler, 1977; Maizels, 1977), and run on the London University CDC 6600 and 7600 computers. The two computers were de-commissioned in mid-1983, and the program library was not transferred to another computer system. Bedford College acquired a DIAD image processing system (Nigel Press Associates, 1983), in late 1983, which replaced the previous facilities. The DIAD is linked to the College's VAX 11/780 computer. Limited computer time was made available on the IDP3000 system at the Royal Aircraft Establishment (RAE, 1978), prior to the acquisition of the DIAD system.

All three systems provided a number of data correction, enhancement, and classification options. The number and quality of the options varied with the system used (Maizels, 1977; Nigel Press Associates, 1983; RAE, 1978). Output images also varied, the results from the Bedford College programs were linked to a microfilm plotter, giving hard copy, monochrome, microfilm chips (positive and negative). Simple line printer output was also available, this aided processing, as, unlike the other two systems, resultant images were not interactively displayed to the operator via a monitor screen.The other systems were linked to high quality colour monitors, used for interactive work, which provided relatively good results when the screen was photographed.

2.4 Landsat Data Correction and Enhancement.

2.4.1 Data correction.

A number of correction (and enhancement) procedures were used during the present study, the main procedures are outlined below.

Correction of both radiometric and geometric factors were made. Radiometric distortions occur when the recorded digital values do not correspond to the ground reflectance values. Geometric distortion occurs where the relative position of features on the imagery do not correspond with those on the ground.

The Landsat system has an array of six detectors for each MSS band. The calibration of the individual detectors changes over time. The satellite contains an automatic recalibration system, however, the corrections may not always fully realign a mis-functioning detector with the other five. In which case a ´sixth-line banding´ effect may be seen on the imagery. Two options were available on the DIAD system to overcome this effect, either a simple replacement of the defective lines by one of their neighbours was used, or a procedure which corrected each pixel using the average of its neighbouring pixels (above and below) was used. Fortunately, most of the Landsat imagery obtained for the Okavango region was of good quality, and ´destripping´ procedures rarely used. Similar corrections were used when a single line of defective data was encountered. These correction procedures are purely cosmetic and do not truly correct the data in terms of the ground reflectance levels.

Image values are also affected by external factors as well as systems problems. Recorded values can be altered by ´air-light´ reflected from the atmosphere (Lillesand and Kiefer, 1979). This haze effect can be decreased by ´contrast stretching´ (an enhancement procedure; see section 2.4.2).

Geometric distortions occur for a number of reasons. The high altitude and small field of view of the Landsat system means that the data is relatively free of panoramic distortions and relief displacements (Lillesand and Kiefer, 1979). the main distortions associated with the data are the result of variations in altitude, attitude and velocity of the satellite platform. Certain of these distortions are predictable, for example the effect of the rotation of the earth beneath the satellite. This can be corrected by off-setting the individual scan lines of an image by a specific amount, this leads to the typical skewed parallelogram shape of corrected Landsat imagery. Distortions associated with changes in the orientation of the satellite vis-a-vis the earth surface are unpredictable. These can be corrected if there is adequate geometric ground reference data available, usually in the form of maps or possibly aerial photographs. Geometric corrections of unpredictable distortions are time consuming and were only used during the present study where absolutely necessary. The geometric correction procedure available on the DIAD system was used, it involved collecting control point data on the ground reference maps and corresponding positions on the imagery using identifiable features on both. A square grid co-ordinate set is required on the map and the line and column numbers are used for the image control points. The control points are used to undertake a ´least squares regression analysis´ which determine the transformation equations which interrelate the geographic and image co-ordinates (Nigel Press Associates, 1983). These equations are then applied to the original image data, which is corrected to the ground co-ordinate matrix. ´Nearest neighbour´ resampling is used to allocate the best fit data (reflectance) values from the original pixels to the new matrix of cells created by the correction.

2.4.2 Data enhancement.

Enhancement procedures are usually undertaken to improve the interpretability of imagery generated from the original data. The usual aim is to increase the contrast between various scene features. The data is then in a form which may facilitate image classification or further detailed enhancement. Image classification involves converting the scene into discrete classes which convey specific information, the result of interpretation.

An enhancement procedure commonly used to improve scene contrast is the ´contrast stretch´. As mentioned above, this is useful in decreasing the effect of haze on image contrast. The contrast stretch is a ´point operation´, (an operation which modifies the brightness values of each pixel in a data set independently). This operation was used to either, enhance the whole image or to selectively enhance parts of the data set to increase the visual contrast between areas of similar reflectance values. The MSS system was designed to accommodate a wide range of scene illumination conditions. The value of the majority of pixels will therefore tend to fall within a small portion of the possible range of 'grey' scale values, resulting in a low contrast display. A contrast stretch of the data expands the range of values, so they are displayed over the full range of possible tonal values (Lillesand and Kiefer, 1979). The range of values for an image can be presented as a histogram (fig. 2.2a) from which the range for any specific stretch can be chosen. The range of values can be set manually, or by computer (which uses the minimum and maximum values for the whole data set to generate an automatic contrast stretch (Maizels, 1977). The usual form of contrast stretch used, was a linear stretch. The range of values of an image were uniformly expanded to fill the total display range of the output devise (fig. 2.2b). This stretch was used as a preliminary enhancement on all of the sub-scenes. One problem is that it assigns as many display levels to infrequently occurring values as to those frequently occurring. This may be overcome by assigning the display range exclusively to a particular part of the range of image values (fig. 2.2d). This is highly selective, and pixels outside of the chosen range become 'saturated' at one or other end of the display range, and appear as blank areas on the resultant image. This type of 'special stretch' was used specifically to enhance patterns within the major sub-divisions of the

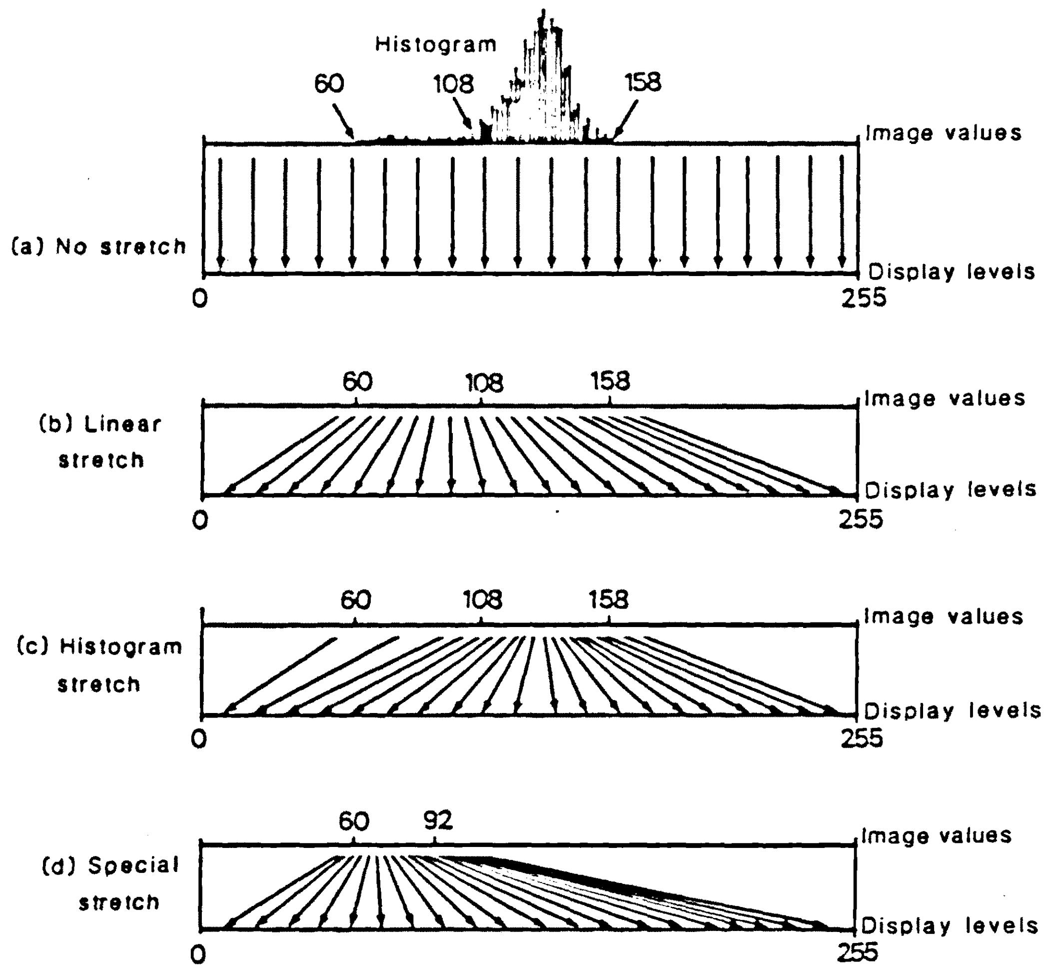


Fig. 2.2 Principle of contrast stretch enhancement
(After Lillesand and Kiefer, 1979)

landscape.

Density slicing provides a more specific enhancement of image data. It is used to provide an objective identification of areas of equal tone across an image. A sliced image is generated by assigning single colours or 'grey levels' to different ranges of tonal values in a single band. This allows objective comparisons of tone between noncontiguous areas (Townshend, 1981a).This is important because perception of a tone can be influenced by those of neighbouring areas. This was used at all levels of analysis during the present study and particularly to identify repetitive patterns within the Landsat scenes, corresponding to patterns in the landscape. A density slice can only be performed on one MSS band at a time and can be regarded as a simple form of classification within the single band.

Enhanced images produced from ratios of multiple band data was also used. Ratio images are prepared by dividing the value of each pixel of a band by the value of the corresponding pixel in another band. Original unstretched data was used to compute the ratio, and a contrast stretch applied to the resultant image. On a ratio image the extreme black and white tones of the grey scale represent maximum differences between the values for corresponding pixels in the two bands (Sabins,1978). The dark tones are areas for which the denominator of the ratio is greater than the numerator and the reverse is true for the lighter areas.

Simple ratios of one band over another, or more complex ratios, were calculated and displayed as images on a colour monitor. From a number of these ratios, which can be stored in the computer memory, false colour composites were generated and further enhanced. Various ratio combinations were tested on selected sub-scenes of the Okavango area.

Specific combinations, associated with reflectance and absorption of light by plant tissue, were tested. In particular, a ratio of MSS band 7 (highly reflected by healthy vegetation) over MSS band 5 (high absorption by plants, for photosynthesis), was used to enhance vegetation patterns (Curran, 1980). A sum normalised ratio of these bands was also tested;

$$\frac{\text{MSS band 7} - \text{MSS band 5}}{\text{MSS band 7} + \text{MSS band 5}}$$

Miller and George (1980) suggest "...that sparse vegetation from a more arid climate might favour the use of the difference of sums ratio."

Another approach to dealing with multiple band imagery, is to apply statistical techniques which operate on all the MSS bands together. Principal Components Analysis (PCA) has been used to enhance multiple band imagery. PCA facilitates interpretation by reducing redundancy between the bands, information that appears in more than one band is considered as being of no less potential value than that in another (Byrne *et al*., 1980). PCA was performed on the Okavango data on the DIAD system. PCA essentially transforms the image values into an alternative set of measurement axes. New axes are positioned within the multi-band data set, such that the first axis accounts for most of the variation within the data set. The subsequent axes account for successively smaller amounts of the variation. The first axis or ´principal component´ often contains the vast majority of the variance in the original data set, effectively providing a "...single-band composite of the multispectral data." (Lillesand and Kiefer, 1979). Black and white images of the individual components were generated or combined as colour composites.

III. Physical and Economic Background to the Study Area.

3.1 Introduction.

The study area is located in the Ngamiland Administrative District of northern Botswana (fig. 3.1). The District occupies nearly one fifth (87,288 square kilometres) of the total land area of Botswana. Ngamiland is entirely within the physiographic region known as the Kalahari Tableland. The Kalahari covers 84.3% (453,041 square kilometres) of the whole country (Fosbrooke, 1971).

The Kalahari is a semi-arid tableland, dominated by dry bush or tree savanna (Field, 1978). The soils are generally poor, consisting of brown, grey or white aeolian sands (Weare, 1971). The Kalahari region is classified as having a dry, steppe climate, with mean annual temperatures over 18°C (BSh), using the Koppen-Geiger Classification.

The Okavango River flows into Ngamiland from the north, the waters spreading out over Kalahari deposits to form a large inland delta. The study area consists of the southern and south-eastern fringes of the delta (fig. 3.2). The presence of the abundant waters of the delta, has created conditions for a number of plant communities that would not otherwise be found in the harsh Kalahari environment. The Delta and the Boteti River are a focus for man and his domestic stock, as well as wildlife.

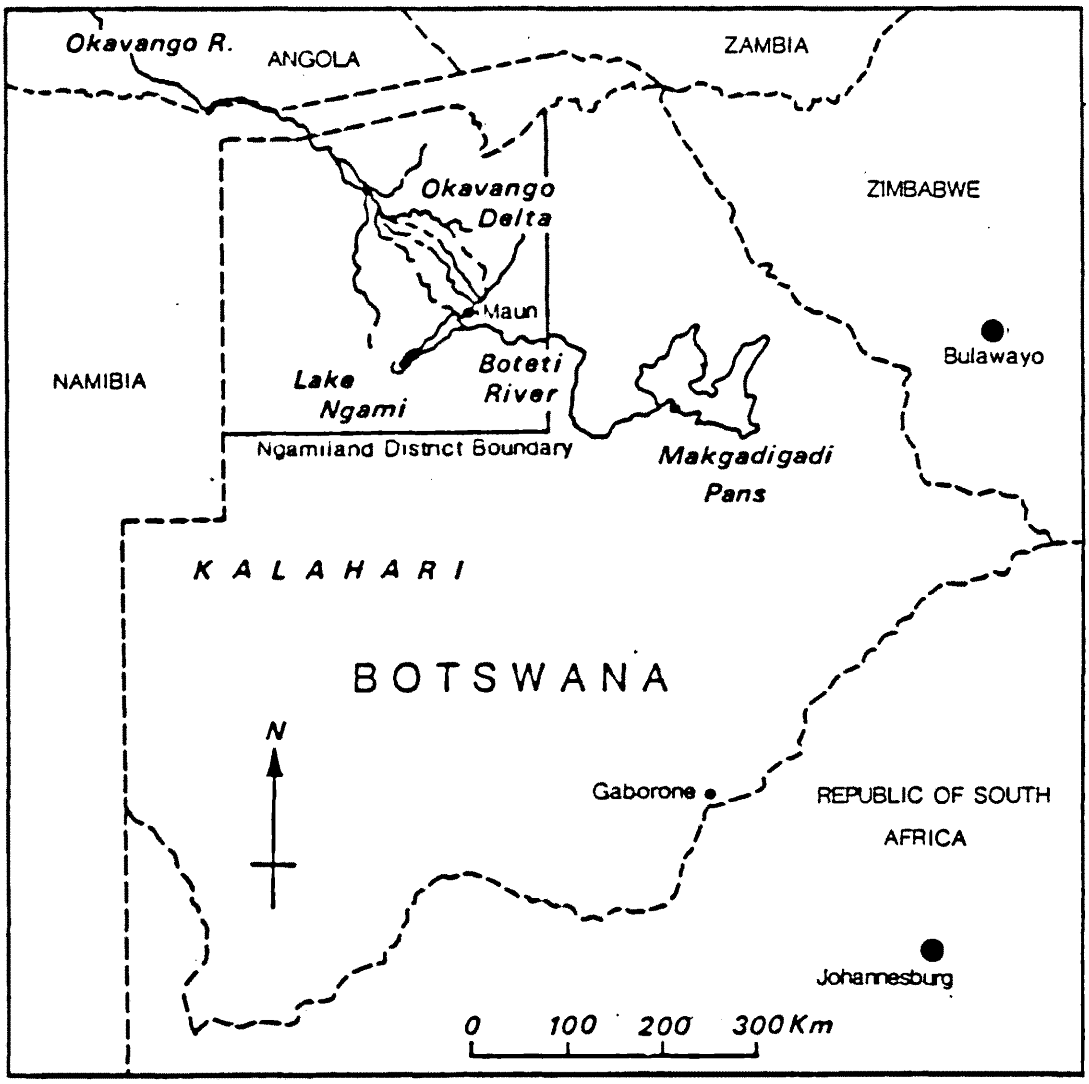


Fig. 3.1 Map of Botswana showing the location of the Ngamiland District.

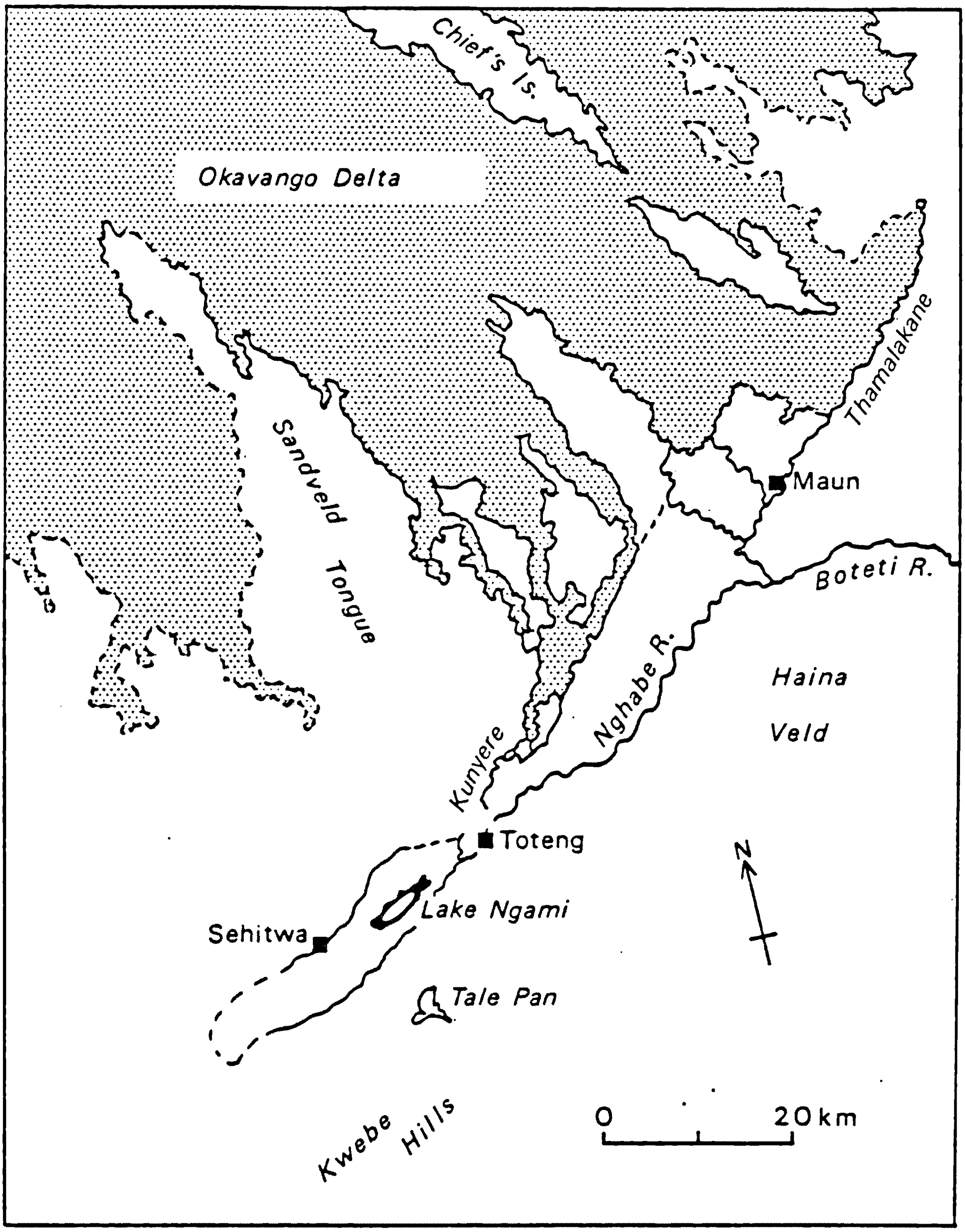


Fig. 3.2 Map showing the location of the study area.

The study area includes the Lake Ngami region to the south of the delta, and extends to the Shorobe-Gomoti area to the north of Maun. It includes the Haina Veld, south of the Boteti. This area encompasses the main zone of both commercial and subsistence agriculture in Ngamiland, as well as the highest human population densities. The interior of the delta is remote, sparsely populated, and unsuitable for stock rearing. The presence of Tsetse fly throughout much of the delta and the northern and eastern fringes, is a limiting factor on the spread of population to these areas. The western margin is populated, but of much less economic importance than the south.

3.2 Geology and geomorphology.

Ngamiland has a scarcity of bedrock exposures, the majority of the solid geology is buried, often very deeply, beneath drift deposits. Within the study region, few outcrops are to be found. South of Lake Ngami a small outcrop of Karoo Sediments is found, and further to the east the Kgwebe Hills form the only high ground in an otherwise relatively flat landscape. The Kgwebe Hills give their name to a formation of quartz-feldspar, porphyry and diabase, which also gives rise to hills further to the south (Hutchins et al., 1976). A picture of the bedrock geology for the majority of the delta region is limited, based on borehole and seismic surveys.

A number of large fault structures can be seen on the Landsat imagery of the delta, these seem to have controlling influences over the direction of flow of the Okavango River itself and of its distributaries. Within the study region, two major faults occur, the Thamalakane and Kunyere. these two apparently control the flow at the distal end of the delta, rivers of the same names occupy parts of the fault zones (see fig. 3.2). Both faults are downthrown to the north-west (Hutchins et al., 1976). To the downthrow side of the Kunyere, the bedrock is thought to be Karoo Sediments (sandstone and shale), with the Kgwebe formation between the faults. South and east of Lake Ngami the drift is thought to overlie rock of the Ghanzi formation (quartzite, shale and limestone).

Overlying the bedrock of most of the region are thick beds of unconsolidated material of Tertiary to Recent age. These deposits are known as the Kalahari Beds, consisting of white and brown, medium to fine grain sands and silts. These beds may be up to 300 metres thick in places, but averaging considerably less. Lacustrine, aeolian and alluvial deposits are recognised (Staring, 1978), but small textural differences make distinction difficult. They are commonly mixed, with some alluvial deposits possibly derived from older lacustrine or aeolian material. The sands are fairly uniformly fine grained over the whole region; sieve analysis (UNDP/FAO, 1977) of sites in and around the delta produced a median grain size of 0.25mm. The results for Maun were, a median grain size of 0.20mm, with lower and upper quartile values of 0.15mm and

0.25mm. Little is know of the succession and structure of these superficial formations.

Associated with the semi-consolidated Kalahari Beds are hard concretionary lenses of calcrete and silcrete.

The hydrology of the delta region is described in some detail by Wilson and Dincer (1976). The Okavango River flows into Botswana from its catchment in Angola, and supplies the flow to the whole delta. The Boro channel supplies the majority of the flow that reaches the distal end of the delta, and the study area. Together with the waters from the lesser Mborogha-Santantadibe system, the Boro supplies the Thamalakane. The latter discharges into the Boteti, which carries the remaining flow away from the delta. A proportion of the water may overspill into the Nghabe, which discharges into Lake Ngami during years of high rainfall in the catchment. A great deal of the flow is lost through evapotranspiration over the delta, only about two percent of the water entering the delta, reaches the Boteti River.

The delta region may be divided into three broad physical zones, which may in turn be sub-divided into characteristic terrain units (see chapter IV). The zones are, the Okavango Delta itself, the surrounding (and in places interdigitating) sandveld country, and various basins that form the terminal sinks for the waters of the delta (Lake Ngami, the Mababe depression, and the Makgadigadi Pan complex). Small areas of upland are found where bedrock is near to the surface or outcrops, however these are not extensive and are considered within the sandveld zone. The study region includes parts of all three physical zones.

Chapter IV describes the terrain classification used in the present study, outlining in detail the geomorphological features of the terrain units and their individual land elements.

The delta area that is included in the study area, is at the distal end of the delta and only seasonally flooded. It consists of a complex mosaic of channels, wide grassy floodplains and vegetated islands. Ridges of ´dry land´ extend into the lower delta; these are regarded as part of the Sandveld zone. The latter zone consists of extensive areas of flat or gently undulating terrain. Over large parts of the region, ancient dune fields form large linear features, which are clearly visible on Landsat imagery. These dominate the terrain to the north and west of the delta, and within the study region are found to the south of Lake Ngami.

The Lake Ngami basin is the only one of the terminal sinks that occurs in the study area. The lake itself varies in extent depending on yearly inflow from the delta. It lies within a basin of some 220 square kilometres. Evidence of ancient shorelines, of a once much larger lake, can be seen from the Landsat imagery. The basin is shallow, forming a level to gently undulating plain. Along the southern edge exists a small scarp slope, and a similar feature (possibly associated with a larger lake), at a distance to the north of the basin.

3.3 Climate.

The Okavango Delta lies in a semi-arid zone, with a distinct seasonal regime of rainfall and temperature. Rainfall occurs during the summer months, mainly between November and April, with a peak in January or February (fig. 3.3). The long term average for Maun is about 450mm. The rainfall regime is a result of an influx of moist tropical air from the equatorial regions during the warm months. When temperatures drop, the moist air is prevented from entering the region by a sub-tropical high pressure belt situated to the north. Most of rain falls during short instability showers and thunderstorms. Rainfall usually exceeds evapotranspiration only in January (Staring, 1978).

The amount of rainfall varies greatly from year to year (fig. 3.4). Periodic droughts affect the whole southern African region. Sandford (1978) has calculated a frequency of one year in thirty-three for a 'severe' drought and one in sixteen for a 'moderate' drought in the Okavango region (a 'severe' and a 'moderate' drought involve a feed deficit in rangeland of 15-40% and up to 15% respectively).

The Okavango region experienced a period of poor rainfall during the early 1960's. A drought resulted in problems for the whole country and large numbers of stock were lost. This was followed by several years of slightly above average rainfall, before another period of poor rains (1968-70). During 1969-70, only 253.8mm of rainfall was recorded in Maun. The 1970's saw increasingly better rainfall figures (which

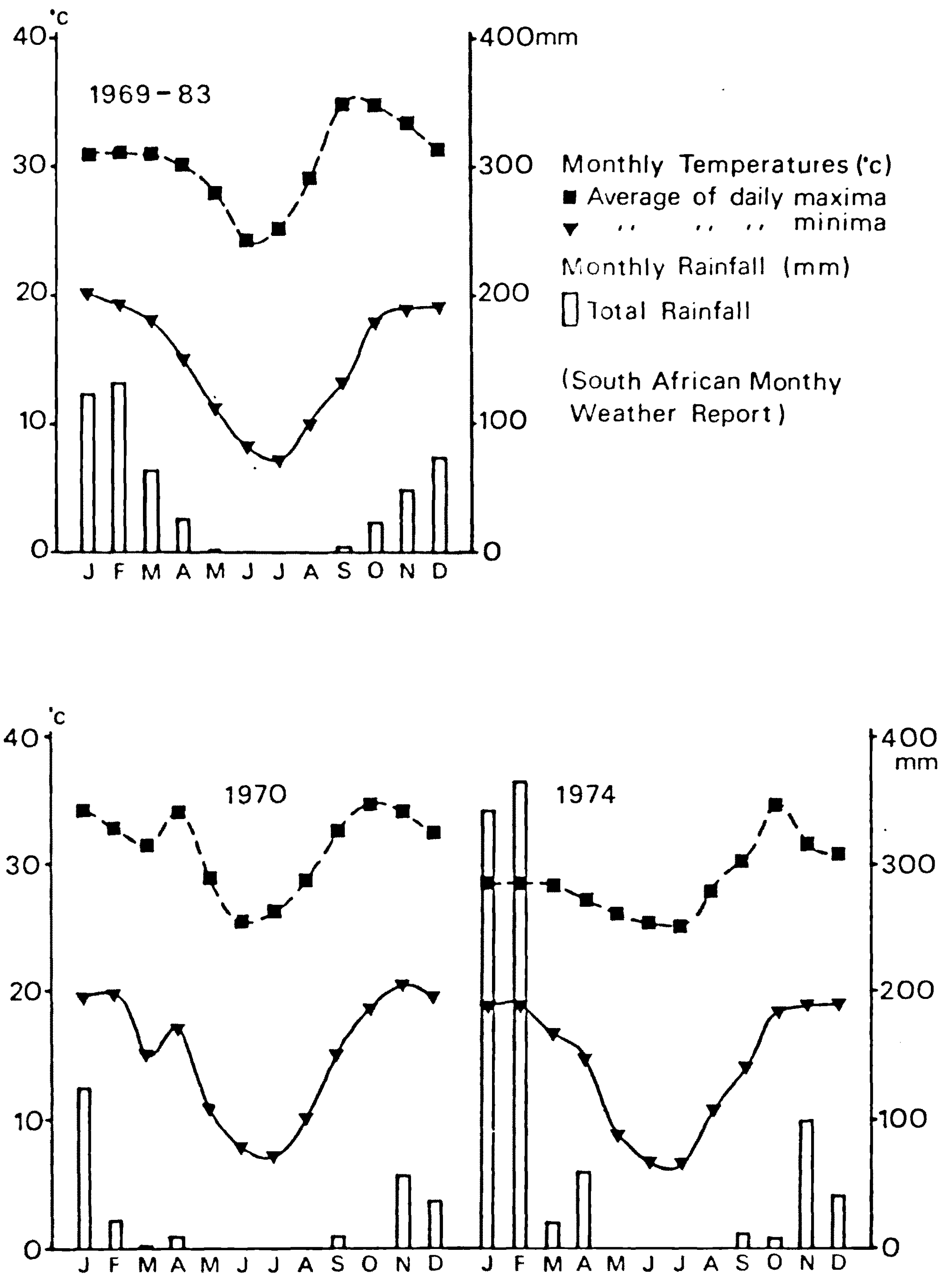


Fig. 3.3 Climatic data, Maun (1969-83, 1970, 1974).

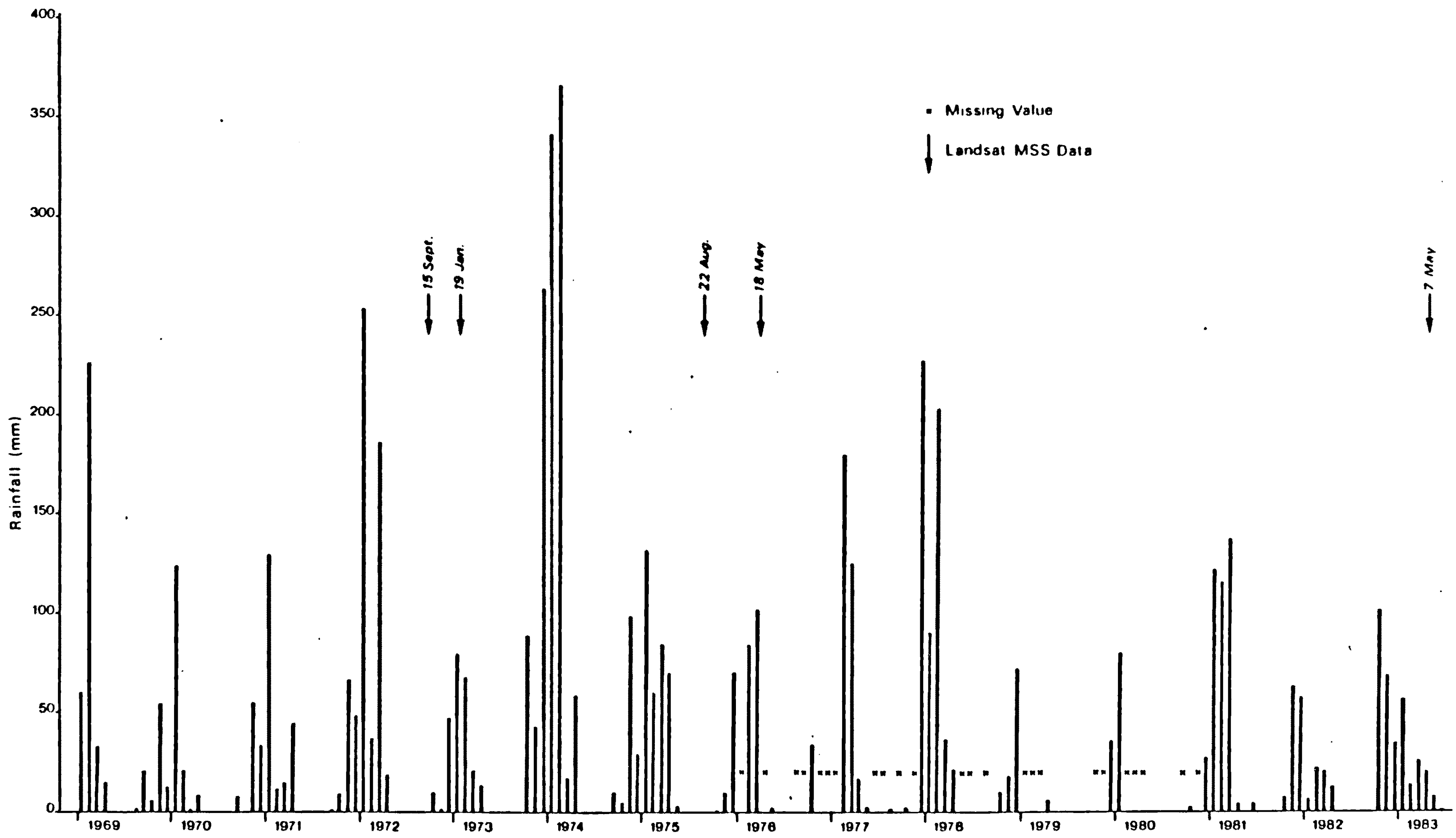


Fig. 3.4 Monthly rainfall data at Maun, 1969-83.

(Source: South African Weather Report, 1969-81, and Weekly Rainfall Report, 1981-83).

persisted until the early 1980's). This period was marked by the 1973-74 rain season, in which 1183.9mm was recorded in Maun. This led to unusually high floods in the lower delta, forcing a halt to cultivation of the floodplains west of Shorobe until 1979 (Andersson, 1976; Staring et al., 1981).

Fluctuations in rainfall over the period since the early 1960's has effected the vegetation of the region. Changes in the woody vegetation of the Sandvelt and associated areas, has been most noticable. After the drought period of the early and late 1960's, tree and shrub cover was low, but with improved conditions, this increased through the next decade. Measurement of woody cover in the Sandveld, using aerial photographic cover (see chapter V), indicates a considerable increase in cover over a ten year period (May 1973 and May 1983, photographic coverage). This increase is confirmed by range surveys carried out at Tsetseku Ranch (APRU, 1978).

Temperatures reach a peak just before the main period of summer rains (September - October), and are at their lowest between June and July (fig. 3.3). Slight differences are apparent between years . Higher than average temperatures were recorded (Maun) following the poor rains in 1969-70 (including an unusual peak in April), while following the heavy rains of 1973-74, temperatures were lower than usual (fig. 3.3). Winter temperatures have been recorded at below freezing on individual days. Frost damage to vegetation can occur. Low temperatures at the end of the dry season may retard regeneration of grasses, even when sufficient moisture is available.

The soil moisture regime of the region has been described by Staring (1978) as ´ustic´. Ustic soils have limited available moisture, although sufficient for significant plant growth when other conditions are favourable (Foth, 1978). The mean annual soil temperature is greater than 22 degrees centigrade in the rooting zone.

3.4 Vegetation

To date, no comprehensive vegetation map of the Okavango Delta region has been published. Williamson (1974), has produced a provisional map based on the interpretation of Landsat photographic products. He identifies six physiognomic vegetation types for the area, however, the scale of the imagery and the inability to further enhance the data, precluded a more detailed investigation. Several vegetation maps for the whole of Botswana have been compiled, the latest being those by Wildeand Barboso (1967), and Weare and Yalala (1971).

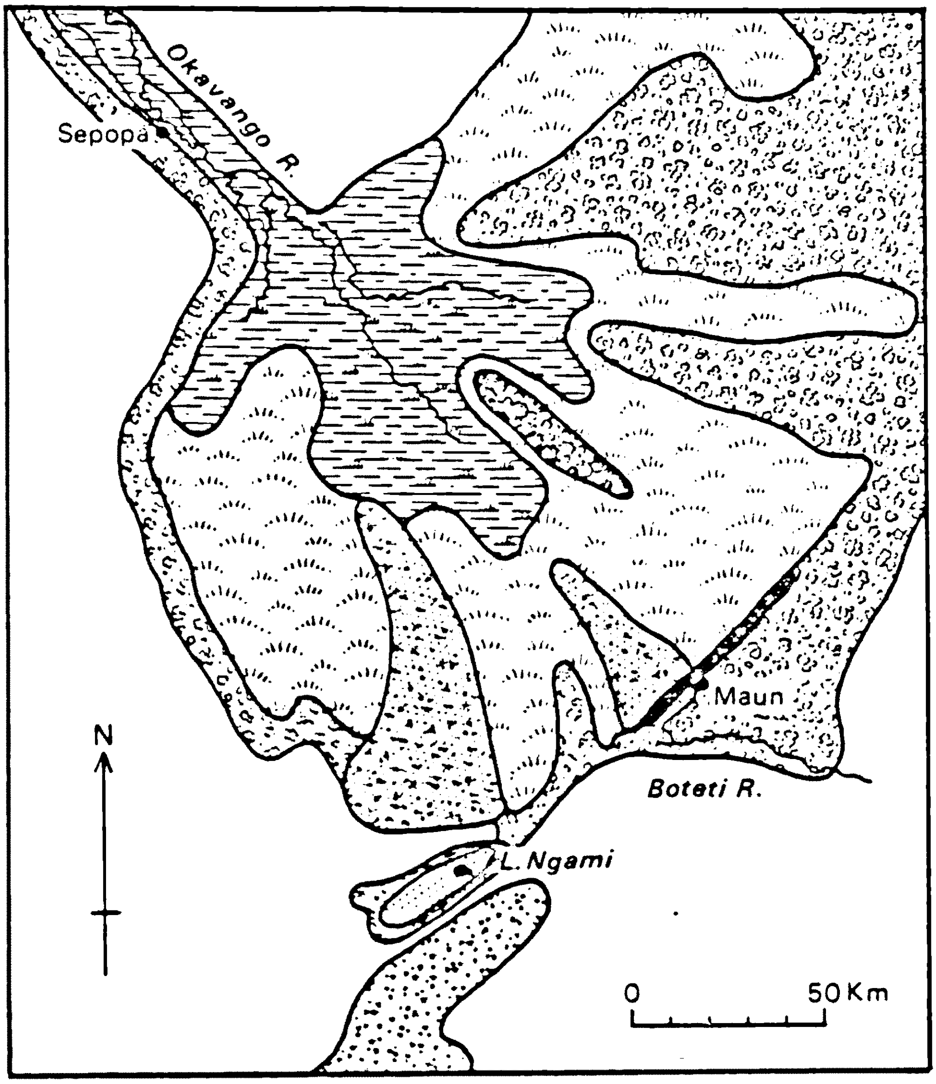
Published material dealing with the vegetation of the area included in the present study, is very limited. Most of the material dealing with the region concentrates on the delta (Astle and Graham, 1976; Biggs, 1976; Dye et al., 1976; Smith, 1976; Raynham, 1979; Lubke et al., 1981). Little detailed information is available for the delta fringes and rangeland areas. Tinley (1966) describes the vegetation of the Moremi Reserve, which has some similarities with the study area to the south. Geobotanical surveys undertaken in the Nwaku pan area provide an outline of vegetation types found to the south of Lake Ngami (Buerger, 1976; Cole and Le Roex, 1978).

The results of range monitoring studies, at Government ranches throughout Botswana, include data from Tsetseku Ranch, south of Maun (APRU, 1975; 1978; 1979). The data covers the period 1970 to 1979, and includes information on woody and herbaceous vegetation, changes in bush density and basal cover of grasses. Additional, unpublished material has been made available by APRU. The ranch was used as one of the main ground data collection sites in 1983.

The vegetation of the region occurs within three main physical zones. The delta wetlands, the sandveld and associated terrain, and the Lake Ngami basin. Within these zones are large variations in the terrain and plant communities (Chapter IV). Figure 3.5 indicates the general pattern of vegetation within the Okavango region.

All of the broad vegetation classes shown in figure 3.5, occur within the study region, except the papyrus zone of the upper delta.

Cole (1982a, pers. com.) regards the Okavango Delta area as a ´vegetation tension zone´, where a number of competing environmental factors are held in tension, any changes in the balance of these factors will lead to changes in the distribution of associated vegetation. The main example of this, is the tension between the dry Kalahari Plateau and exotic waters of the delta, changes in flow and distribution of the waters can lead to major changes in the vegetation



Papyrus (Sudd)

Cymbopogon–Panicum–Andropogon (aquatic grassland)

Lake Ngami Savanna Grassland *

Terminalia sericea Tree Savanna (Northern Kalahari Tree & Bush Savanna)

Boscia albitrunca–Acacia spp. Tree Savanna

Acacia spp. Tree Savanna

Colophospermum mopane Tree Savanna

Okavango Fringe Woodland *

After Wild & Barboso, (1967) & Weare & Yalala*(1971)

Fig. 3.5 Vegetation map of the Okavango Delta region.

patterns. This has occurred to the west of the delta, where the cessation of flow through the Thoage system has led to a change in vegetation, from those characteristic of wetlands, to those of semi-arid areas.

The aquatic grasslands occupy the floodplains of the lower delta region, which are seasonally inundated by the waters of the Okavango catchment. The dominant grass species found on the floodplains (within the study region), is Panicum repens (Lubke et al., 1981; Staring et al., 1981). Dense stands of reed (Phragmites mauritanus), and sedges (Cyperus spp.) may be found along the central parts of the floodplains or at the edge of pools and lagoons. On higher ground P. repens is often replaced by other grass species, especially Cynodon dactylon. Scattered islands of dry land exist above the normal level of seasonal inundation. These islands generally possess a fringe of dense, mixed woodland, with the central part occupied by low shrubs and scattered trees or by grassland.

The grassland of the Lake Ngami floodplain differs somewhat from that of the lower delta. The dominant species is C. dactylon, with Eragrostis sp. and Echinochloa sp. along the edge of semi-permanent water bodies. The pattern of the vegetation is dependent on the level of flooding of the basin from year to year.

The areas classified as 'tree savanna' by Wilde and Barboso (1967) occupy the dry Kalahari Plateau. these areas are classified according to their dominant or characteristic species. In many parts of the study region, the composition of the woody component is a mixture of species, with dominance dictated by local conditions. For example, Terminalia sericea (which is characteristic of one of the zones), dominates sandy ridges, while the depressions between, are dominated by species of other genera (Acacia spp., Grewia spp.). In the depressions, and especially in the vicinity of rain pans, T. sericea may be totally absent.

In certain circumstances, a single species forms almost pure stands. In the case of the Colophospermum mopane tree savanna, a monospecific canopy often occurs. C. mopane is an aggressive species, often ousting competitor species. In the Moremi Reserve, C. mopane forms woodland, but does vary to savanna woodland in places (Tinley, 1966). A similar situation is found to the north and east of Maun. However, human activity may have altered the structure to some extent, the woodland is less dense and (possibly due to fire) areas of low C. mopane coppice-like scrub are found. South of Maun the C. mopane vegetation becomes less dominant, eventually forming 'islands', within areas dominated by other species. C. mopane was rarely encountered in any numbers in vegetation dominated by another tree species (Acacia spp., Terminalia spp.), in the study region.

Fringing woodlands along the floodplain edges occur throughout the delta. Much of this woodland is restricted to a narrow ribbon, often only 50 to 100 metres in width. In certain places the woodland becomes more extensive and well developed, usually associated with more permanent water conditions (Biggs, 1976). In the study region, extensive zones of the fringe woodland are associated with the major channels at the distal end of the delta (the Thamalakane, Shashi, Boro, Xotego). The woodland is formed of a mixture of species, with no overall dominant. prominent species include, Garcinia livingstonei, Ficus sycamorus, Lonchocarpus capassa, Croton megalobotrys, and the palm, Hyphaene ventricosa. The woodland is partially evergreen. In places a characteristic palm woodland occurs, with H. ventricosa as an emergent, above the general canopy level.

Within the various terrain types that make up the study region, the vegetation displays much more variety in terms of structure and composition than is outlined above (section 4.8.2).

3.5 Economy.

3.5.1 Introduction.

The Okavango Delta region falls within the Ngamiland District of Botswana, which in the 1971 census was recorded as having a population of over 53,000 (Afriyie,1976). Of this number, over 40,000 live in or on the margins of the delta. The location of the population is largely determined by the incidence of tsetse fly. Settlement is restricted to the north, west, and south-eastern fringes of the delta.

A hierarchy of settlement exists, dominated by Maun, the administrative and commercial centre of Ngamiland. Maun has about twenty-five percent of the District's population. A number of larger villages form local centres, with small outlying villages and scattered communities (designated either as 'lands' or 'cattle-posts') in their periphery. Nearly half of the population of the delta live in these small communities (UNDP/FAO, 1977).

About eighty percent of the local people are involved in subsistence agriculture. The main activities are dryland arable farming, cattle and small stock rearing, and flood recession agriculture.These activities have a major impact on the local environment (see below). The exploitation of natural resources such as timber, reeds and fish, and the tourist industry (low volume/high cost), put little pressure on the delta at present.

3.5.2 Livestock.

Cattle are traditionally regarded in Botswana as a sign of wealth, and are the preferred form of agricultural activity. Small stock (mainly goats and to a lesser extent sheep), are kept for local consumption. Small stock tend to be restricted to the immediate area around human habitation, and locally contribute to soil erosion through overgrazing of the vegetation.

Cattle production is an important source of income to the Ngamiland District. Estimated offtake in the mid-1970's was 16,000 head of cattle per annum; worth about R1.3 million (South African Rand) to the local economy (Min. of Agriculture, 1976). An expansion in production over the 1980's may occur, depending on the economic viability of commercial ranching in the Haina Veld, (south of the Boteti). This will depend on the adequacy of bore hole water supplies (UNDP/FAO, 1977). The Botswana Meat Commission (BMC) has had built a modern abattoir near Maun, at a cost of 7 million Pula (Times, 1982). This came into production during 1983, to supply frozen beef for export.

Cattle are widespread along the southern and western fringes of the delta. The presence of Tsetse fly provide a 'barrier' to cattle further east than Shorobe. An estimation of the total cattle population of Ngamiland in 1971 (following a decade of droughts) was 206,000. The next few years saw a substantial increase to a figure of 314,000 in 1975 (Min. of Agriculture, 1976). The distribution of the herd throughout the District is uneven (table 3.1, fig. 3.6). The Botswana Livestock Corporation estimate that 50% of all cattle purchased by them in Ngamiland, originate in the Lake Ngami area, with a further 10% from the Boteti area.

Water is an important factor in the distribution of the cattle population. The greatest densities are found near the rivers and shallow wells (fig. 3.7). Boreholes have been sunk where water is not otherwise available, for example in the Haina Veld area.

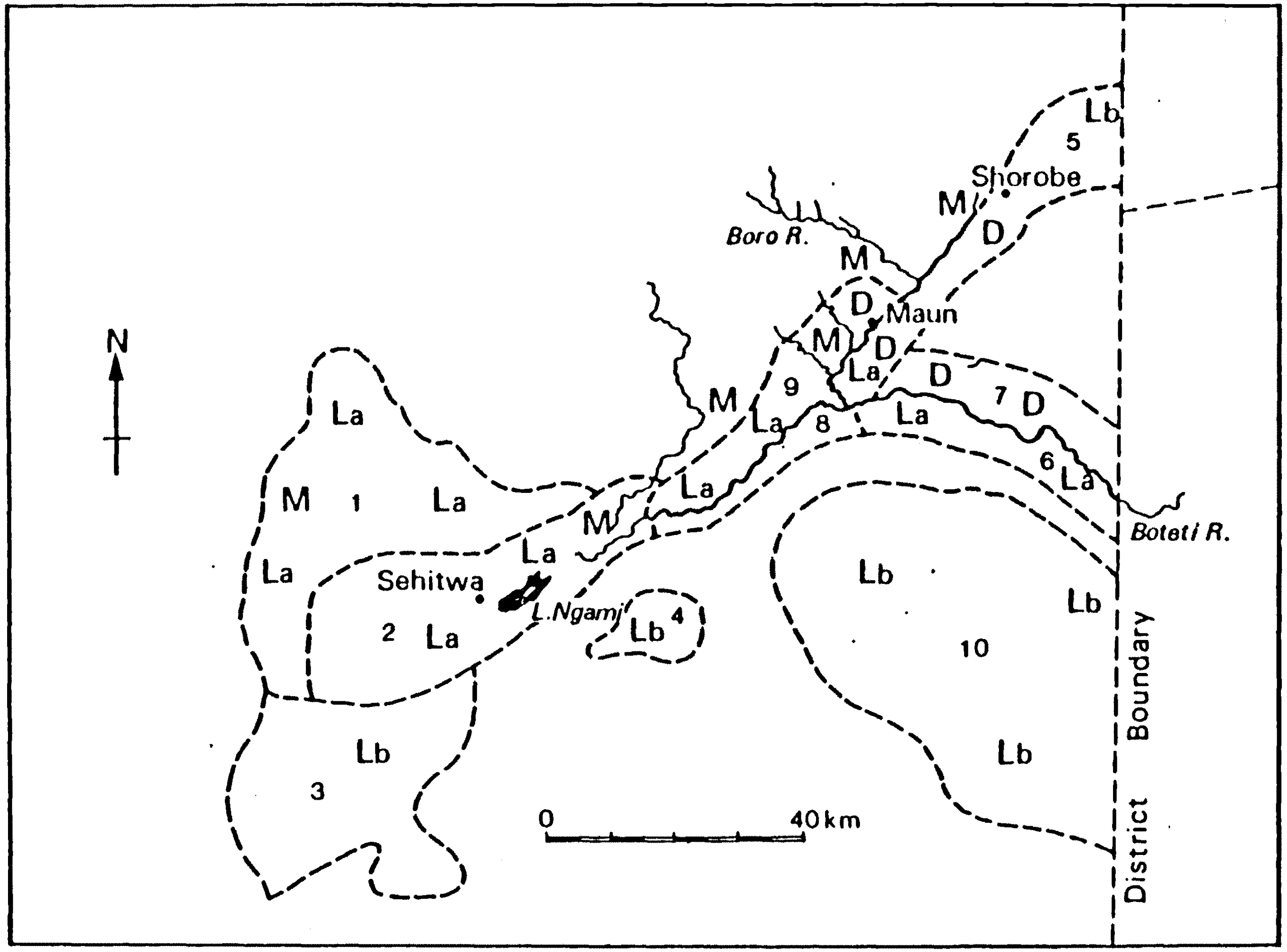
Table 3.1 Distribution of Cattle - Southern and Eastern Delta Margins (1975).

	Livestock units	% increase (1971-75)	ha/LSU	Water Supply
Lower Thoage	38718	138	6	W B
Lake Ngami	32419	64	4	L W
Southern L. Ngami	8085	15	23	W B
Kgwebe	2773	-	-	W B
Thamalakane	5173	14	25	R W B
Boteti R. (South)	8533	66	6	R
Boteti R. (North)	9253	111	4	R
Nghabe R. (East)	5420	170	1	R
Nghabe R. (West)	6937	181	1	R
Haina Veld	14895	34	11	B

(Source; UNDP/FAO, 1977).

LSU = livestock unit
(mature animal of 500kg. liveweight),

W = wells, B = boreholes,
R = river, L = lake.



LEGEND

1. Lower Thoage
2. Lake Ngami
3. Southern L. Ngami
4. Kgwebe
5. Thamalakane
6. Boteti R. (south)
7. Boteti R. (north)
8. Nghabe R. (east)
9. Nghabe R. (west)
10. Haina Velt

La Livestock (High Stocking Rate)

Lb Livestock (Low Stocking Rate)

M Molapo Farming

D Dryland Farming

(After: UNDP/FAO, 1977).

Fig. 3.6 Present landuse of the study area.

Fig. 3.7 Cattle at a well, Lake Ngami.

All forms of livestock production within the region are based on expoitation of the natural vegetation. Extensive areas of natural vegetation used in this way can be defined as 'rangeland' (Heady and Heady, 1982). The 'potential carrying capacity' of the majority of rangeland in the Okavango region, is about 16 hectares per livestock unit (LSU) (Field, 1978). North-east of Maun the figure improves (12ha/LSU), however, much of this area is infested with Tsetse fly. The potential carrying capacity is that amount of rangeland required by an individual animal, to maintain maximum health and productive efficiency, without deterioration of the range. It is regarded as the optimum stocking rate. However, in the Okavango region, actual stocking rates tend to be much higher than the calculated optimum (table 3.1). The potential carrying capacity of 16ha/LSU is that calculated for uncontrolled grazing (which represents the current situation over the majority of the region), for controlled ranch conditions the figure is 8ha/LSU. The figures in table 3.1 suggest that a large part of the rangeland within the study area is potentially at risk from the effects of overgrazing. During the mid-1970's a UNDP/FAO (1977) study concluded that there was no large scale degradation of range in the Okavango region. The period of deteriorating climatic conditions during the early 1980's has led to greater pressure on the land. Certain areas, especially Lake Ngami and the Nghabe River zones were in poor condition in 1983.

Nearly the whole Ngamiland District herd is kept under traditional methods of husbandry. The only fenced ranches at present, are those run for educational and research purposes by the Government, for example Tsetseku Ranch. The traditional form of herding is based on the cattle post system. An individual herd is kept on communal land, away from the village, often by poorly paid labourers. The quality of management is poor, the main concern of the owner being to maximise private wealth in livestock at the expense of the common wealth of the rangeland (Von Kaufman, 1978). A system based on common usage, locks each individual "...into a system that compels him to increase his herd without limit - in a world that is limited." (Hardin, 1968).

A common attitude is that the greater the number of cattle owned, the greater the chance of some surviving a drought, ´drought insurance´ (Alidi, 1978). This attitude, together with a drive to maximise individual wealth, leads to overstocking and initiation of conditions not dissimilar to the effects of drought itself, ´management induced drought´ (Buck, 1978; Sweet, 1982).

Throughout Botswana, burning of the communal grazing lands is prohibited by legislation (APRU, 1980). However, large areas of the country are still affected, including the Ngamiland District. Burnt areas are clearly visible on Landsat imagery, and are found on both the dry land areas (e.g. sandveld), and in the zones of seasonal flooding (e.g. ´melapo´). The burns may be accidental in some cases or started deliberately, to clear moribund vegetation and to stimulate new growth. Burning, as a range management tool, needs careful control and may be harmful if incorrectly used.

3.5.3 Arable agriculture.

The arable agriculture in the region is predominantly for subsistence, and this activity occupies the efforts of a large majority of the population (Afriyie, 1976). Lack of transport and marketing infrastructure, together with poor soils, restricts cash crop production (Thompson, 1976). Some surplus production may be sold for cash in Maun and the larger villages.

The main cereals grown are sorghum and maize, with a variety of other crops including; melons, beans, groundnuts, pumpkins, gourds and sugar cane (Campbell, 1976).

Cultivation is of two main types, rainfed dryland farming ('masimo a pula'), and flood recession farming in the melapo areas ('masimo a bokgola'). The later area is most favourable for maize production, seasonal inundation increases fertility by flushing silt and organic matter into the area from the upper delta. Flood recession agriculture accounts for about a fifth of arable production in the region.

The UNDP/FAO (1977) give details of an unpublished Government report, which estimated the area of land cleared for cultivation in the delta periphery, using aerial photographic cover. The cleared area amounted to about 18 5000 ha, of which 7,000 ha was under crops.

3.5.4 Water development.

During the last century, a number of major proposals for development of the delta as a water resource have been put forward. Potten (1975) and UNDP/FAO (1977) outline the various projects. However, to date most projects have been small scale, through local initiatives and some formal aid projects (Staring et al., 1981). these projects have principally involved slight alterations in channel courses, impounding and regulation of flood waters for agriculture, and clearance of vegetation choked water ways. A number of changes in the hydrology of the delta have occurred in the past hundred years, almost totally as a result of natural processes (plant succession, papyrus blockages, and deposition of sediments).

Modifications to the hydrologic regime of the delta may affect the vegetation of the marginal areas. Firstly, by directly altering the composition of vegetation communities through changes in the water table and soil moisture conditions. Secondly, increased exploitation of water resources may lead to localised pressure on the environment, for example pressure from stock at bore holes leading to denudation of vegetation cover and to soil erosion. Up to 73% or more of the Ngamiland District herd could be affected by major changes in hydrologic conditions. Only some 22% of the herd exists in areas known to have bore holes independent of recharge from the delta.

Poor soils and the lack of marketing infrastructure have restricted the the introduction of irrigation schemes. The Ngamiland District is thought to posses between 5-10,000 ha of potentially irrigable land (Thompson, 1976).

IV. Terrain Analysis and Mapping Using Landsat MSS Data.

4.1 Introduction.

A number of different landscape types occur in the southern margin region of the Okavango Delta area. It was considered important to identify and map these differing components of the landscape as the basis for a detailed resource study. A base map, showing the various terrain types, together with a description of the definitive and associated physical characteristics of each, can serve several useful purposes.

Firstly, it can provide an effective method of summarising the characteristics of a region, and a useful framework for planning further detailed survey and analysis.

Secondly, by classifying the region into areas displaying various inter-related characteristics (eg. vegetation, soils and relief), it may be possible to make inferences concerning other properties that are not directly observable (Townshend, 1981c).

Thirdly, the allocation of boundaries to ´classes´ within the landscape, serves to establish target areas within which detailed analysis may be undertaken and limits to which extrapolation of results may reasonably be made.

The classification of the terrain (of remote areas) into distinctive units, often on the basis of topography, has usually involved the use of aerial photographs. Ground data is often supplemental, providing a check on the photo interpretation and providing additional data unavailable from the main source. Therefore, the quality of the survey will depend largely on the type and scale of the photography and on the skill of the interpreter. If other forms of imagery are used, for example Landsat, these points still apply.

A number of terrain classifications have been developed. These generally aim to sub-divide the landscape "...into areas with a recurring pattern of topography, soils and vegetation." (Christian and Stewart, 1953), and having "...within them common physical attributes that are different from those of adjacent areas." (Cooke and Dornkamp, 1974).

Various schemes have been formulated, for example the 'land-systems' approach. This was originally developed by the Commonwealth Scientific and Industrial Research Organisation in Australia (CSIRO), for rapid surveys of unmapped regions. It has been adopted and modified by other organisations including the Military Engineering Experimental Establishment (MEXE, 1965) and the UK's Overseas Development Administration (ODA) Land Resources Division (LRD) (Ministry of Overseas Development, 1970). In the land systems approach a mosaic of aerial photographs is laid out, and the boundaries between distinct areas are marked. A boundary is usually accepted if a distinct difference is apparent between landform assemblages on either side of it.

The land systems approach uses changes in relief (topography) as the main definitive characteristic when dividing the landscape into its component parts. Other classifications have tended to follow this basic formula (MEXE, 1965; Wright, 1972). Alternative approaches to landscape classification, for example, use of vegetation as an index of environmental variation, were not technically possible using the black and white aerial photography available when the Land Systems approach was developed. The development of other remote sensing data systems provides the opportunity to analyse alternative approaches. The use of relief as the main definitive characteristic may also be inappropriate in certain environments, and an alternative classification essential. For example, where changes in relief over large areas are very slight.

Landsat imagery lacks stereoscopic capability and therefore relief cannot not be directly measured. The Landsat system records the reflectance of solar energy from the earth's surface and may give an indirect impression of relief through shadow effects, especially if sun angle is low and vegetative cover sparse. King (1982) notes the lack of stereoscopy, but suggests that a land system approach can be used, if "...supported by selected airphoto interpretation and fieldwork sampling ...". However, in many areas where topography is gentle, no direct impression of relief is evident from imagery, this is the case for much of Botswana. Changes in vegetation patterns and other ground cover features may indirectly indicate variation in topography, suggesting that a different approach to that of land systems analysis is needed if Landsat data is used.

Landsat digital data has a number of advantages over conventional aerial photography (even allowing for a lack of stereoscopy), for terrain analysis. It provides a synoptic view of a large area. This overcomes the problems of mosaics, where tones and textures between adjacent photographs may vary. If two or more Landsat images are needed, computer programs are available for joining scenes, using the digital data. If a digital processing facility is available, detailed areas within the main image can be examined rapidly, and actual reflectance values of features compared objectively, across the whole scene. The MSS system also provides the opportunity to utilise other methods of terrain classification, than that based on topography.

Any such method must be based primarily on reflectance characteristics of ground cover features. Topography may modify the reflectance characteristics of a given ground cover type, but is generally not the main physical property affecting reflectance. Therefore, the primary classification should be based on the reflectance responses of the main ground cover features. These will vary with particular environments, but will usually consist of vegetation and soil cover, with some exposed bedrock and detritus, and surface water bodies.

The rationale for the land systems approach, based primarily on topographic differences, has been justified by Stewart and Perry (1953) as follows:

> "The topography and soils are dependent on the nature of the underlying rocks (ie. geology), the erosional and depositional processes that have produced the present topography (ie. geomorphology) and the climate under which these processes have operated. Thus the land system is a scientific classification of country based on topography, soils and vegetation correlated with geology, geomorphology and climate."

If Landsat data is used (instead of stereoscopic photographs), the appropriate definitive characteristics are no longer changes in relief, but in the reflectance response of the terrain features. Therefore, the classification of terrain using this data maybe be justified as follows:

> The particular spectral responses recorded, of a given area, are characteristic of various ground cover features. The responses of these features (vegetation, soils, water bodies, exposed geology) are influenced by a number of biophysical properties. The pattern of these features are dependent on the nature of the underlying geology, the geomorphological processes of which the present topography is a product and the climate under which these processes have operated.

> Therefore, an assessment of terrain based on Landsat data, is a scientific classification of landscape based on the spectral characteristics of ground surface features correlated with geology, topography, geomorphology and climate.

Given this definition, a particular ground cover/surface component may be used to classify the landscape, including relief. Cole (1982b) notes that "The vegetation of any area reflects the interplay of current climatic and edaphic conditions, and the legacy of past climatic and geological events." To this may well be added, the landuse history of the area. Vegetation may therefore provide a useful index of environmental conditions and a means of classifying terrain.

Within a target area, boundaries of the various levels of a classification may be allocated on the basis of specific spectral responses. The sub-division may begin at the broad scale (as with land systems), working towards the particular (land units), or as in the case of Wright's (1972) site-analysis approach, the lowest landscape units are defined first, then grouped together to form the equivalent of land systems.

Individual terrain 'types' (for example land systems), may vary in size from tens to hundreds of square kilometres. This may be a reflection, in part, of the nature of varied landscapes. However, this is difficult to test, due to the lack of specification as to the amount of internal variation permitted within any system (Young, 1976). The smallest separate component parts of a landscape are regarded as areas within which environmental conditions are uniform (Young, 1976). In practice these are the smallest units that can be distinguished as distinct, internally homogenous areas on the imagery. In the case of Landsat imagery, this may represent an area of distinct spectral response, characteristic of a plant community, over a particular soil type, formed from a particular lithological unit. Thus a technical scale limit to terrain analysis exists, where it is no longer possible to further sub-divide the landscape into its component parts using a particular form of imagery. The resolution of photography or other remotely sensed data controls this, together with the scale of the 'hard copy'. However, this does not necessarily imply the need for the highest resolution of data possible, but choice of image scale and resolution should reflect the particular environment and the objectives of survey. A choice of imagery is not always available, in which case an understanding of the limitations imposed by resolution and scale must be taken into account.

4.2 Terrain analysis in Botswana.

In Botswana, land systems mapping has been carried out in the east of the country (Bawden and Stobbs, 1963; Bawden, 1965), and for part of the Okavango Delta (Astle and Graham, 1976; Astle, 1977). The latter survey did not include within its boundaries, the area of the present study.

A soil survey (Staring, 1977) of the Okavango delta and its margins employed a method of terrain analysis similar to that of land systems. The region was subdivided into 'natural regions', 'terrain units' and 'land elements' (the latter two classes corresponding closely to 'land systems' and 'land units'). A terrain unit is defined as having "...internal uniform patterns of ecological conditions." This survey did include the area of the present study within its boundaries.

The soil survey used aerial photography (1:70 000, black and white) and Landsat photographic products (1:620 000, including colour composites), to map the boundaries of the units. The use of preprocessed Landsat data limited the use of the data for this kind of survey, to visual interpretation of a form similar to aerial photographic interpretation. Many of the advantages of Landsat digital data could not be utilized. At the scale of 1:620 000, the imagery could not be used to define the smaller landscape units, and therefore the study was limited to the use of black and white photography at the 'land element' level of classification.

Although the survey's terrain classification provides some useful information, it cannot be considered adequate as a framework for other surveys of the area, for a number of reasons:

a) Although the survey included a form of terrain classification, it was produced primarily to provide a practical, spacial framework into which the results of a soil survey could be fitted, which was then used to provide an assessment of land use capabilities. It provides only limited information on a number of factors which are important in the context of the present study, (vegetation patterns, composition, physiognomy and structure, and surface water conditions).

b) The survey provides no information on how the Landsat data was used to define terrain units (or land elements), especially the relationship between ground features and their spectral responses. Descriptions of colour and tone are given, however, these do not seem to correspond to a 'conventional' Landsat colour composite image (bands 4, 5 and 7, with blue, green and red filters, respectively) for the 'given' features. No information is given concerning the types of preprocessing and enhancement used, or of band combinations.

c) The data employed in the survey, was not temporally contiguous, posing problems concerning the comparability of the Landsat data and ground surface conditions as recorded in the field. Field work for ground data was carried out during 1978 (for the study area) and compared with air photographic cover from 1973 and Landsat data from 1975. The data sources were close in terms of seasonality (remotely sensed data, March; ground survey, May). However, the incidence of rainfall during this period was irregular, casting doubt on the comparability of the data sources.

In any survey utilizing remotely sensed data sources, accurate interpretation of ground conditions is facilitated by temporal contiguity of this data with ground survey information. If temporal contiguity is not possible in practice, data should be collected at times of similar environmental conditions, for example at the same season. The importance of timing may depend to some extent on both the method of data collection and the ground features to be analysed. In the case of Landsat data, the need for contiguous data is probably more important. The imagery generated from the digital MSS data allows inferences to be made about ground features from the reflectance responses recorded. These reflectances may vary greatly with changes in environmental circumstances, for example, following heavy rainfall.

d) Only limited remotely sensed data was available at the time of the soil survey. The scale of photography used was 1;70 000 (1:40 000 scale was available for much of the area, from August 1969, but may have been thought unsuitable). The Landsat photo products used for interpretation were small scale (1:620 000) and only a single image for each area (three separate images were used to cover the whole delta).

The scale of the data will partially determine the level to which the landscape is sub-divided (land systems are best identified at about 1:125 000 scale, and land facets at 1:20 000 to 1:30 000 scales, Cooke and Doornkamp (1974).

e) The use of simple, small scale Landsat photo products, leaves the survey open to one of the main criticisms of the use of remote imagery for terrain analysis. Wright (1972) suggests that a classification is likely to be strongly influenced by the more evident contrasts in patterns seen on photographs. This could lead to a final sub-division into land units which differ both in kind and in order of magnitude. This criticism would apply equally to the Landsat photo-products used in the soil survey. This can be overcome by various forms of digital enhancement of Landsat data. These can improve the quality of the resultant imagery and subsequent interpretation.

4.3 Terrain analysis of the south eastern margin of the Okavango Delta region.

The following survey was undertaken to:

a) Provide an effective summary of the landscape characteristics of the study area, based on the spectral responses of ground features recorded by the Landsat MSS system.

b) Assess the effectiveness of various image enhancement and classification procedures for the interpretation and classification of terrain using Landsat data.

Preliminary analysis of the study area was undertaken using available satellite and aerial photographic coverage, together with published maps and material describing the area. The final classification was based on a combination of information, field survey data, Landsat data and aerial photographic material.

For the 1970's, only limited landsat coverage is available for Southern Africa, (which was out of the range of a Landsat receiving station). Subsequently, a station was set up in the Republic of South Africa, thereby increasing the availability of data.

A number of Landsat scenes were obtained, as both preprocessed black and white negatives (for each MSS band), and in the form of computer compatible tapes (CCT's);

CCT's -	15 September	1972	ID = 1054 - 07571
	19 January	1973	ID = 1180 - 07574
	22 August	1975	ID = 2212 - 07445
	18 May	1976	ID = 2482 - 07402

Initially, the photographic negatives were used to produce black and white prints and positive transparencies, of each MSS band for whole scenes (at 1:1 000 000 scale).

Transparencies were used to generate false colour composites (using a colour additive viewer) at various scales up to 1:200 000. Colour additive viewing assists the interpretation of multiband imagery, as it effectively combines three bands of MSS data in one image. The human eye is also better able to discriminate colour than grey tones, by up to 100 times (Slater, 1975). A colour image is generated by superimposing three of the MSS bands, each with one of the primary light colours (blue, green and red). The examination of the photographic products was undertaken mainly as a preliminary to processing the digital data.

The study area was covered by photo-maps at 1:50 000 scale, these provide only basic information, but were useful in locating major features on the imagery (rivers, roads, and settlements). These features were mapped to provide reference points.

The study area was initially sub-divided into a number of broad classes on the basis of visual interpretation of colour, tone and texture of scene elements of the Landsat photographic products. Imagery of various dates was examined, and a number of different colour composites produced (by varying band/filter combinations in the additive viewer), in an attempt to enhance scene features.

The conventional colour composite band/filter combination, of bands 4, 5 and 7 with the blue, green and red filters respectively, provided the best discrimination over the whole scene. Individual bands were useful for identifying particular features, for example, MSS band 7 (1972 image) allowed the rivers seen on the 1:50 000 map series to be clearly identified.

The study areawas sub-divided into classes where a change in the character of the recorded spectral responses was evident, and where the area enclosed contained a repetitive suite of reflectance patterns or was relatively homogenous. No attempt was made at this point to relate the internal reflectance characteristics of each class to particular landscape features.

A map of the classes identified was produced (c. 1:500 000 scale), using information from all the available Landsat imagery. The map base was produced using the image for 19 January 1973 (colour composite MSS bands 4,5 and 7 (fig. 4.1) and single MSS band 5.

4.4 Provisional classification of the study area.

Broad areas containing recurring patterns of reflectance responses were identified. In some cases, colours, tones or textures might be seen repeated in adjacent classes, but the combination of factors and their pattern varied sufficiently for a distinction to be made. Seasonal and yearly differences in colours and tones, between images, were noted. Differences in pattern and texture were not generally evident.

The provisional classification is given below. The main distinguishing scene characteristics are described for each class (colours and tones refer to the image of 19 Jan. 1973 (fig. 4.1) unless stated). Nine provisional classes were identified.

a) Class 1. Areas containing a dense, generally irregular, network of low reflectance levels, seen as black or dark red, with intertices of high reflectances, pale blue to white. These areas are found at the distal end of the Okavango delta.

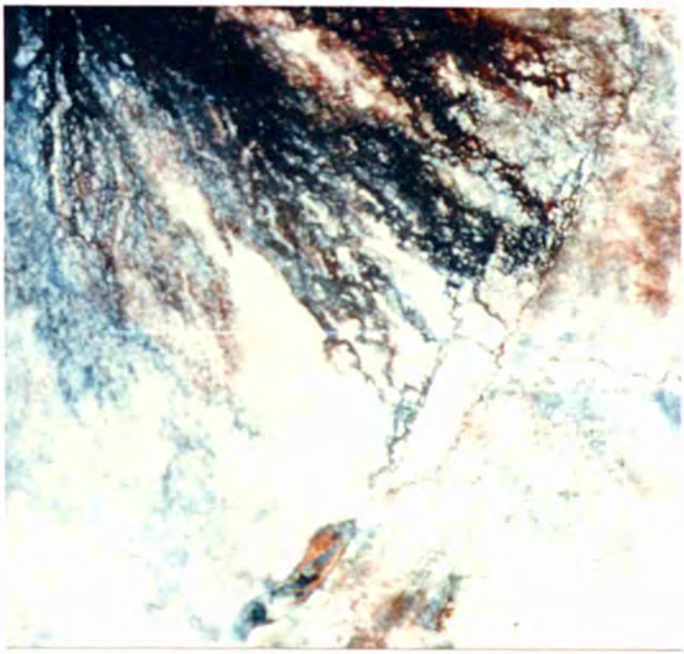


Fig. 4.1 Landsat colour composite of the study area
(January 1973).

b) Class 2. Ribbons of low reflectances, black or dark red. These are associated with the major river channels at the distal end of the delta, and can be clearly identified on the 1:50 000 photo-maps.

c) Class 3. An area of (generally) smooth reflectances, forming essentially a concentric pattern. The colours and tones varied markedly between seasons and years. Higher tones generally occurred at the outer limit of the concentric pattern. The class is clearly associated with the Lake Ngami basin, the centre of the class is seen as black on a number of the images, suggesting a water body.

d) Class 4. An area of mottled, medium to high reflectances, varying in colour from grey to blue, with patches of white. Fine networks of very high responses in all bands are evident in this class, as well as a number of distinct curved features. This class occurs mainly to the north of Lake Ngami.

e) Class 5. Areas of mottled, medium to high reflectances, especially in band 7 (1973). This area is most distinct as separate from adjoining areas on the 1973 image, where the class varies from medium and pale orange-brown to brown- grey. This class occurs to the north of the Boteti River.

f) Class 6. Areas of mottled, medium to high responses in all bands. This class is similar in pattern to class 5, but is dominantly pale to medium grey and blue in colour, through to white. This is found throughout the study area, but dominates the regions to the east and west of the Nghabe river, south of the Boteti.

g) Class 7. This area is very similar to class 6 in its main characteristics, but is distinguished by clusters of very low responses which form dark brown mottled areas.

h) Class 8. Areas of high to medium reflectance, with localised patches of low response (dark brown). This class varies widely in colour; red-brown, orange-brown, yellow, grey and blue occur as various tones. This class is particularly distinguished by the the presence of broad east-west trending bands of distinct spectral responses.

i) Class 9. An area of mottled, medium to dark tones, varying in colour from brown, through green to grey and blue. This class displays a series of distinct linear features trending north-east to south-west. The east-west trending bands of class 8 cross into this class, but the two classes remain fairly distinct.

The boundaries between classes varied, some were less clear than others, in places the reflectance patterns seem to form a continuum from one class to another, with no clear boundary at all. This suggested that certain classes might have common ground features. This is especially true of classes 6 and 7, where it was difficult to allocate a boundary. Classes 1, 2 and 3 generally had very well defined boundaries with other classes. Boundaries between any two of the classes 4, 5, 6, 7 and 8, were often less distinct.

Having initially sub-divided the study area, sub-scenes (of the whole Landsat scene) were identified for digital enhancement and detailed analysis. These sub-scenes were selected to include a part of several of the major sub-division previously identified. The approximate locations of these sub-scenes were identified on a print MSS band 5 of the whole Landsat scene. MSS band 5 was selected because it provided good contrast between many scene elements, and locational features were clearly visible. At the sub-scene level, each pixel within a given area is displayed, that is a display of every column by every row of the data.

The analysis of the sub-scenes had a three-fold objective:

a) To check the validity of the provisional broad scale sub-divisions.

b) To assess the applicability of various digital enhancement and classification procedures, for terrain analysis using Landsat data.

c) To produce detailed 'maps' of spectral response patterns, within the previously identified broad sub-divisions. These maps were later used as the basis for field checking and comparison of the reflectance patterns with aerial photographic data.

Pixel line and column coordinates were used to locate and extract the sub- scenes from the digital data space. The methods of extracting a data set and of subsequent enhancement procedures varied with the image processing system used.

The images were analysed and maps produced by two methods, namely, visual classification (of the patterns on the basis of colour, tone and texture, from digitally enhanced imagery), and by using computer assisted classification techniques (supervised and unsupervised). it is important to note the difference between classification and enhancement. A classification consists of a number of steps by which the image data is converted into specific, discrete classes that highlight information, and involves interpretation of the imagery. An enhancement transforms the data into a more interpretable form (Lillesand and Kiefer, 1979).

4.5 Preliminary interpretation and classification of sub-scenes.

4.5.1 Visual methods.

Prior to visual classification, a number of procedures were used to enhance the sub-scenes. Certain enhancements were specifically employed to improve the imagery for terrain analysis. Density slicing and special histogram contrast stretches, were used to objectively identify areas of equal tone across an image and to improve the contrast between various scene components. Band ratios were used in an attempt to isolate and identify specific landscape features.

Once suitable imagery had been generated, it was used to map the spectral response patterns on to a map base. At this stage, the smallest component parts of the image were plotted, and classified according to colour, tone and texture. The boundaries were also classified as either, well defined, adequately defined, or poorly defined. In some cases the boundary between two units was difficult to define, when a gradual change of colour and/or tone between two distinct areas existed.

4.5.2 Computer aided methods.

Digital image processing carried out prior to field survey (1983) used either the Bedford College image processing library of programs or the IDP3000 system.

Unsupervised and supervised classification programs (Chandler, 1977) were used on selected sub-scenes. These procedures were used to sub-divide the imagery automatically on the basis of reflectance values, to overcome problems of visual interpretation.

The unsupervised classification (POLYDIV, polythetic divisive cluster analysis) (Maizels, 1977) involved finding which pixel values are similar enough to one another to allow them to be grouped together. Polythetic classification means pixel values may be grouped as the result of similarity between only some of their attributes and not necessarily all of them. The procedure is divisive, the pixels are initially placed into the two most dissimilar groups, based on a 'similarity matrix' of all observations. "The decision on where to split the groups is accomplished by calculating the shortest distances (i.e. Euclidean distances) between pixel values in 3-band (or 4-band) space, and ensuring that the variance (based on mean distance of each observation from the relevant mean value) between each group exceeds the variance within each group." (Maizels, 1977). The group with the greatest variance is then itself subdivided. This is repeated until the number of groups originally specified in the procedure, is reached.

The advantages of unsupervised classification are, that no ground data or similar information is needed to generate clusters (involving subjective selection of training data), and the resultant map therefore provides an objective division of the target area, based on its reflectance characteristics.

The supervised classification (program SOUP (Chandler, 1977)) required the input of selected training sets of data which were considered typical of a ground feature or cover type (the procedure is described in detail by Maizels (1977)). Air photographic cover was used to aid selection of the training sets.

The training sets were used to calculate a measurement vector (i.e. the mean density value), and the covariance matrix for each band. The Euclidean distance between each pixel and each training set vector was calculated, and the pixels were allocated to the training set which is the most similar (Maizels, 1977). The decision boundaries between different classification groups was based on mathematical decision rules, involving probability calculations. A threshold level, defining the maximum distance from any group mean at which a pixel could be allocated to a group, could be given and a 'bin' class of unidentified pixels generated. Multiple training sets were used for each group, to overcome any possible problems caused by haze or slight topographic differences across the image.

The supervised classification has the advantage, that during the interpretation of the classified map, each class can be associated with the known ground feature used to provide the original training set.

4.6 Assessment of classification procedures.

The detailed analysis of sub-scenes did not result in any major changes to the provisional classification of the study area. At the sub-scene level it was possible to define the boundaries between classes more precisely. At this level the individual components which form the distinctive pattern of spectral responses within each class, could readily be seen.

The classification procedures used, varied greatly in their ability to provide a useful classification for the study area.

The unsupervised classification (POLYDIV) proved unsuccessful. Beyond the first second, or third division of the data, the displayed classes became fragmented and no recognisable pattern (when compared with aerial photographs), was found. Cole and Owen-Jones (1977), using the same POLYDIV program, encountered varying results from this method, depending on the type of landscape investigated. They suggested that the failure of the classification for certain terrain was due to extremely heterogeneous spectral responses, in their case associated with rugged terrain. Areas of natural terrain often exhibit a high degree of continuous spatial variation (as opposed to the discreet compartmentalisation of many man-made landscapes), hence the difficulty in defining some of the class boundaries within the study area. The classes displayed for the first few divisions of the data, often corresponded closely to the classes defined earlier, which were clearly seen on the conventional colour composite.

The supervised classification (SOUP) also proved unsuccessful. The subjective choice of training sets greatly affected the resultant classes, which varied considerably with different data sets. Lack of detailed knowledge of ground conditions meant that training sets were necessarily arbitrary, even with the use of aerial photographs.

Visual classification, despite certain problems inherent in this subjective method, proved to be the most practical and useful method at this stage. Each discrete scene element, allocated a boundary, was coded according to colour and tone using a key adopted from Cole and Owen-Jones (1977). Nine levels of increasing density of tone are used. The individual elements could then be allocated to classes on the basis of the coding. This allowed a large degree of flexibility in classification, which is important prior to field verification. The code allowed subtle differences in the landscape to be identified in the field, within selected classes. This was not be possible with the other classifications, and difficult when using unclassified images with no imposed structure.

Visual classification is, however, time consuming and open to the criticism of being highly subjective. Different individuals may classify tones and colours differently, and a single interpreter may not be consistent across an image (one of the problems associated with the use of aerial photography, that the analysis of digital data can potentially avoid). During the present study, the coding of scene elements was continually checked against other parts of the imagery with the same coding; variation appeared to be minimal, especially with regard to colours. Another problem associated with visual classification is that colours and tone also vary depending on the particular contrast stretch used on any sub-scene, making direct comparison between sub-scenes difficult. A degree of overlap between adjacent sub-scenes aided detection of variation.

Density slicing proved useful in detecting areas of similar tonal values across an image, helping to even out potential errors of visual classification. Band ratios were not generally helpful, as interpretation of the results was difficult, lacking ground data. Images produced from combinations of MSS band 7 (highly reflected by healthy green vegetation) and band 5 (highly absorbed, for photosynthesis) were used in order to try and detect variations in green vegetation cover. Both the simple ratio of MSS bands 7/5, and the 'vegetation index' (Curran, 1980) (7-5)/(7+5), produced images which when compared with aerial photographs gave an indication of the general distribution of vegetation cover, however, the imagery and photographic data were not contemporary and so no clear comparison could be made.

The classified maps were compared with the available aerial photographic data prior to ground survey. A provisional interpretation of the main physiognomic categories of vegetation (woodland, tree and shrub savanna, grassland and aquatic) was made. Topographical and hydrological features were noted from the examination of stereo pairs of aerial photographs.

4.7 Ground reference data collection.

4.7.1 Introduction.

Ground reference data is perhaps the most important sub-set of all reference data used for the interpretation of remote sensing imagery. This data is gathered directly in the field, and may take a number of forms.

Ground data is particularly important in establishing the relationship between image data values and the physical characteristics governing the response of specific surfaces as they exist at ground level. In the case of Landsat MSS data, this involves the characteristics which govern the reflectance (absorption and transmission), of solar radiation in the four MSS bands. The value of each individual pixel is a product of the reflectance values of all the ground features within the pixel area. Thus ground data collection will cover, as far as is practical, all features occurring in sample areas, the detail being determined by cost, time or environmental constraints.

4.7.2 Timing.

Permission for research in Botswana, and liaison with the appropriate Government departments concerned with aspects of the study, precluded field investigations prior to 1983.

Ground data collection was carried out between late April and late June 1983 (at the end of the summer). This period was chosen for a number of reasons;

a) Most of the vegetation in the area should still be in good condition at this time. This was important in terms of both, identification of species, and for an understanding of the structure and physiognomy of the vegetation patterns. In the event, no problem was encountered in identifying woody species, even though Botswana had experienced low rainfall in the 1982-83 season. However, identification of grasses was hampered by the poor condition of most specimens.

At this period of the year, grass cover is usually declining rapidly (to a low point in July), in the Sandveld savanna zones (APRU, 1975). This was more marked in 1983, due to low rainfall over the previous few years and increasing grazing pressure. Low grass cover aided the evaluation of woody cover estimation in the Sandveld zone, using Landsat data (chapter V).

b) An aerial photographic survey (black and white, 1:50 000) of the whole delta was flown during this period (the study area was covered between 7 and 16 May). Tsetseku ranch, run by the Animal Production Research Unit (APRU) of the Botswanan Ministry of Agriculture, and used as one of the main ground survey sites during this study, was also photographed (colour, 1:10 000), on 16 June. Sets of both photographic surveys were obtained from the Botswana Department of Surveys and Lands.

A Landsat image for the 7 May was obtained subsequent to ground survey from the South African Landsat receiving station. Together with the ground survey and aerial photography, this provided the study with a hierarchy of contiguous data.

c) Timing of field work at the end of the summer coincided with a fall in both temperatures and rainfall, both of which improvedworking conditions, and occurred before the main annual flooding of the lower delta. The decrease in rainfall improves accessibility over the study area, which lacks all-weather roads. The rainfall is, however, out of phase with the annual flooding of the delta. The main rains fall from November to March in the main catchment in Angola, and although maximum flooding of the Okavango at Mohembo (on the Namibian-Botswanan border) is in March, it takes a further five months to peak at Maun (Wilson and Dincer, 1976). This meant access was possible into parts of the study area, liable to flooding, until late June.

4.7.3 Local conditions.

The area under investigation is in the more remote north of Botswana. A road contructed from calcrete exists along the main axis of the study area, running from Maun to Sehitwa near Lake Ngami, and another from Maun towards Francis town. Most of the other motorable tracks and cut-lines are simply loose sand, making a four-wheel drive vehicle essential. The area is well covered with tracks, many of which have been mapped and can also be seen on aerial photographs. However, since the publication of the 1:50,000 map series, many of the tracks and cut-lines have become overgrown and new ones have been cut. Accurate location away from major features such as tracks, river channels, pans and fencelines is difficult. The terrain for the most part is gently undulating with few distinctive landmarks visible at ground level.

4.7.4 Selection of ground characteristics.

Several sets of ground characteristics can be identified and measured in the field. An understanding of the basic factors controlling the reflected solar radiation is important. Ground data collection for terrain analysis or a resource survey, as in the present study, is unlikely to allow for the time, precision and instrumentation needed to measure these factors, but a basic understanding of them is required. Outlined below are some of the main biophysical properties affecting radiation characteristics (recorded by Landsat MSS sensors) (Justice and Townshend 1981a).

a) General; topography, azimuth and elevation of radiation source, atmospheric interactions, and instrument/sensor characteristics.

b) Vegetation; plant cell structure and pigmentation, physical form of the plant (eg. leaf orientation), and leaf moisture content.

c) Soils; texture, moisture and soluble salt content, humus and iron oxide, mineral composition, micro-relief, and weathering products.

Data may be collected on directly observable features of a target area. This usually involves collecting information at a number of sites and using this data to interpret the imagery and extrapolate over the target area.

There are a wide range of ground features for which data can be collected. The choice of which specific properties and their priority within the study are determined by the objectives of the survey.The main groups of important field characteristics are; surface form properties, surface material types and characteristics, and vegetation types and distribution.

Surface form is important in the way it affects image characteristics. Slope angle and aspect are important determinants of the amount of solar radiation incident upon any ground surface. Together with the affects of macro-relief, differences in micro-relief influence the reflection of incident radiation from any given surface. Most surfaces fall between the ideal 'specular' reflectance (mirror-like) and the ideal 'diffuse' reflectance of radiation. Smooth surfaces tend toward specular reflectances and rough surfaces towards a diffuse reflectance.

Surfaces may change their characteristics with time, for example smooth clay surfaces may crack and flake as they become dry, thereby altering their reflective character. Any differences between time of imaging an area and collection of ground data must take such factors into account.

A number of soil surface features were recorded, including texture, structure, and colour. Estimates of texture were made in the field by the standard method of moistening the soil and working it between finger and thumb. Structure was noted, however, for most of the study area the dominantly sandy soils were structureless, occasionally a thin 'crust' had formed and would break up into extremely fragile platy structures. Platy structures were also found in dry clay pans. Soil colour was recorded using a Munsell colour chart. The soil surface throughout the study region was generally dry (even shortly after rain), this will affect the reflectance characteristic of the surface, therefore, unless otherwise stated, the Munsell classifications used in this study represent that for 'dry' soil. Any evidence of bare rock surfaces or other features such as salt deposits or calcrete outcrops were noted. The amount of bare surface and vegetation cover was estimated. A detailed soil survey including augering or excavation of pits was not undertaken, as these tend to be time consuming and provide little extra information on reflectance characteristics. Some detailed soil data was available from published sources (Buerger, 1976; Staring, 1977). In the context of the present study, detailed knowledge of surface materials become most important where plant cover was incomplete.

Vegetation types can be categorised in various ways. The most useful criteria for the present study were, 'structural', 'physiognomic' and 'compositional'. Physiognomic criteria refer to the appearance of communities and separates groups such as woodland, grassland and scrub. Structural criteria are those concerned with the arrangement of vegetation in space, this includes height, size of crowns and density of canopies. A precise description of the physical properties of a plant community can be produced using these criteria. Data on species composition is important for a number of reasons.

a) Variations between species in their spectral responses (related to differences in leaf structure and pigmentation).

b) The presence of 'indicator' species. Many plant species occur within a specific range of environmental conditions, and their presence is indicative of these. For example, in the Okavango region, Terminalia sericea is indicative of deep sands (Tinley, 1966; Cole, pers. comm.).

c) The utility or disadvantages of certain plant species in the rangeland environment. For example, those woody species which tend to encroach on rangeland at the expense of grass cover.

4.7.5 Ground data collection.

The collection of ground data fell into two main categories. Firstly, a number of transects were used to gather data over a large part of the area. Secondly, detailed data was collected at selected sites. The latter data was primarily collected for analysis of particular vegetation types (see chapters V and VI), but provides additional useful information for terrain analysis. Figure 4.2 shows the main transect lines, and the position of the selected detailed study areas.

The transects were located parallel to main roads, tracks, fence and cut lines, which could be located on air photographs and/or the 1:50 000 topographic maps. The major roads and tracks were also visible on Landsat imagery. The transects were selected to cover at least some part of all the original, main sub-divisions of the area, based on spectral response patterns. However, due to problems of accessibility and time, transects were not extended far into the Haina Veld or into the region south of Tale Pan.

Transects were covered either by vehicle or on foot. Distances were recorded either by using the vehicle's odometer or by pacing. As data was gathered, distances were logged and used to transfer the information to the 1:50 000 base maps. While logging data, information was simultaneously marked onto air photographs, when possible, and compared with maps of spectral response patterns prepared from the Landsat imagery. Paced transects proved reasonably accurate, several transects at Tsetseku ranch were paced several times, the greatest

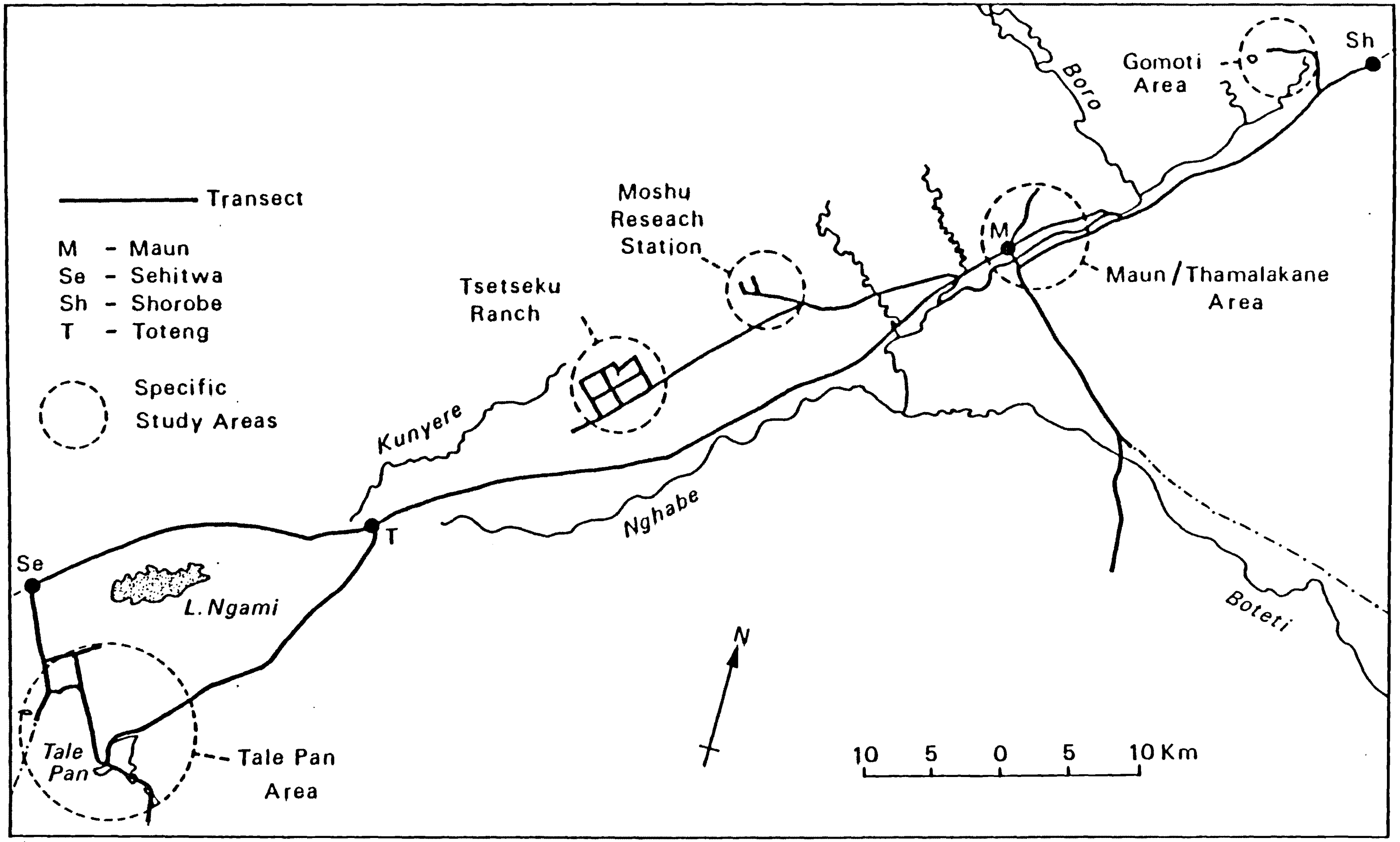


Fig. 4.2 Location of transects and main survey sites.

difference found, over a 2.3 kilometre transect, was approximately 1.5% or 34.5 metres.

Both on foot and by vehicle, frequent stops were made to record data and take photographs, as changes in the terrain were encountered. The ease with which it was possible to gather data depended on the density of woody vegetation, in places it was necessary to create an offset at right angles to the main transect, to ensure a representative assessment of the site.

Preliminary examination of existing air photographic cover and Landsat imagery suggested that physiognomic changes in the vegetation patterns was the main factor affecting variation in spectral response patterns in the study area. However, changes could also be attributed to differing structural criteria, (for example, size and/or spacing of a canopy), and possibly to compositional changes. Examination of stereo pairs of air photographs indicated that the topography of the area is unlikely to directly affect spectral response patterns, the region is generally level, with areas of gentle rises and intervening depressions. Some changes in the pattern of spectral responses were obviously attributable to relatively localised phenomena, such as open water, pans, and human settlements.

Changes in physiognomy of the vegetation was therefore taken as the basic division of the terrain along the transects. The physiognomic categories, which refer to the general appearance of vegetation, were qualified and sub-divided on the basis of structural properties. Within these categories, data was recorded on, vegetation composition, soil, topography and landuse.

a) Structural properties. Two main properties were recorded; an estimate of cover and the general height of the canopy or dominant layer of the vegetation. A visual estimate of cover was made for particular layers within the vegetation of any category. Cover is defined as the proportion of the ground occupied by a perpendicular projection on to it of the aerial parts of the vegetation type being assessed (Greig-Smith, 1957). The following classes were used to describe cover;

scattered	(<10%)
sparse	(10 - 20%)
medium	(20 - 40%)
dense	(40 - 60%)
very dense	(>60%).

Height of the canopy layer was estimated in metres, and note made of the height of any emergents, for example, where low tree and shrub savanna occurred, both the height of the scattered tree layer and the general shrub layer were recorded. General notes were made of other structural properties of interest, such as stratification and size of crowns.

b) Compositional properties. The dominant and sub-dominant species within the physiognomic category were recorded. Other common species were noted, including, where possible, the main species in the non-dominant layers.

c) Soil surface features related to reflectance characteristics. This included the factors discussed above (texture, structure and colour), as well as an estimate of the amount of surface litter cover and bare soil. These estimates were classified as follows;

very low	(<10%)
low	(10 - 20%)
medium	(20 - 40%)
high	(40 - 60%)
very high	(>60%).

d) Topography. A general description of the topography, including approximate slope angles and the periodicity of dune crests where they occurred, were recorded. Further topographic data was available from air photographs. Some local information detailed was available, from the work of Staring *et al*. (1981) in the Gomare area, and for Tsetseku ranch, where a transect was leveled as part of the present survey.

4.8 Final interpretation and classification.

4.8.1 Introduction.

The field data, together with contemporaneous Landsat and photographic cover, was used to produce the final Classification. Additional information was available from several published and unpublished sources (Vegetation: Buerger, (1976); Cole (unpublished material); Smith, (1976); Tinley, (1966). Soils and geomorphology: Buerger, (1976); Staring, (1978); Staring et al., (1981). Other minor sources are cited in the text).

The preliminary classification, of the Landsat imagery, produced nine broad sub-divisions of the study area. Subsequent interpretation and classification, based on the 1983 data, reduced the number to eight. One of the original sub-divisions being sub-ordinated within another.

To avoid confusion with other classifications, the following terms are applied. The main sub-divisions (those areas possessing internally common attributes, and differing from those of adjacent areas), are termed ´terrain types´. The component parts of a terrain type, which form it´s ´common attributes´, are termed ´terrain components´. A third class, intermediate to the others, is termed a ´terrain sub-type´, (this only occurred within the terrain type ´Kalahari sandveld´).

The terrain types are described below. Within these, the main classification into terrain components, is on the basis of vegetation physiognomy and structure.

All reference to Landsat image characteristics refer to conventional colour composites, generated from the 1983 data, unless stated otherwise. Figure 4.3 shows imagery of the whole study area (May 1983).

Areas of human settlement, fields and roads are evident from the imagery. These are characteristically white to very pale blue on colour composites. These features occur throughout much of the study area, they are only discussed where they occur as an important part of a terrain type or component.

Particular colours and tones are repeated in more than one terrain type. These can often be distinguished from one another on the basis of pattern, shape, and location with regard to other scene components. For example the spectral responses of a rain pan can be broadly similar to an area of human settlement, as seen on a colour composite image (pale blue to white). However, various diagnostic features can be used to visually distinguish between the two; settlements rarely display a distinct boundary with surrounding areas, tracks and roads may be seen to converge on the area, the ´component´ is often mottled without any regular pattern internally, while pans often have a distinct boundary (in many cases with dense woody fringing vegetation), and display a concentric patterning, occasionally with a darker area in the

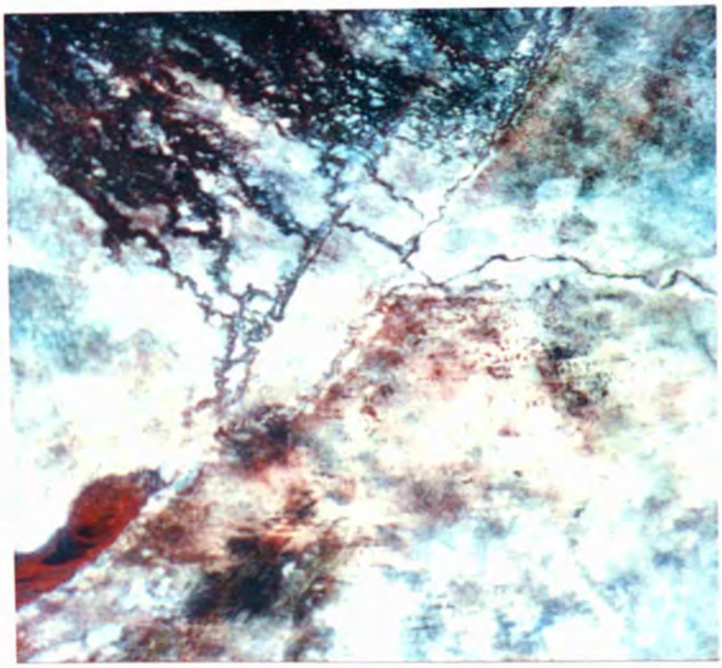


Fig. 4.3 Landsat colour composite of the study area (May 1983).

centre of the pan (related to clay accumulation).

4.8.2 Terrain types.

In the following section, the order in which the terrain types are described is based on a gradient, from types which are annually inundated by the waters of the Okavango system, to dryland types which receive all their moisture as rainfall.

The following terrain types were identified (the provisional classes into which these were classified, are given). The terrain types are shown in figure 4.4.

a) Lower Delta Overflow Plains (class 1).

This ′type′ consists of two main elements; wide grass covered overflow plains (free from woody vegetation), seen on Landsat imagery as a diverging and converging pattern of interconnecting floodplains, alternating with low islands. The island fringe is often marked by a narrow zone of dense woodland, (see fig. 4.5), which indicates the upper limit of flooding during normal years (the islands may be inundated during extreme conditions).The floodplains, known locally as ′melapo′ (singular - ′molapo′), are characterised by flooding for at least part of the year. They vary between 100 and 1000m wide, and are flat to gently undulating. The boundaries between the two elements can clearly be delineated on Landsat imagery.

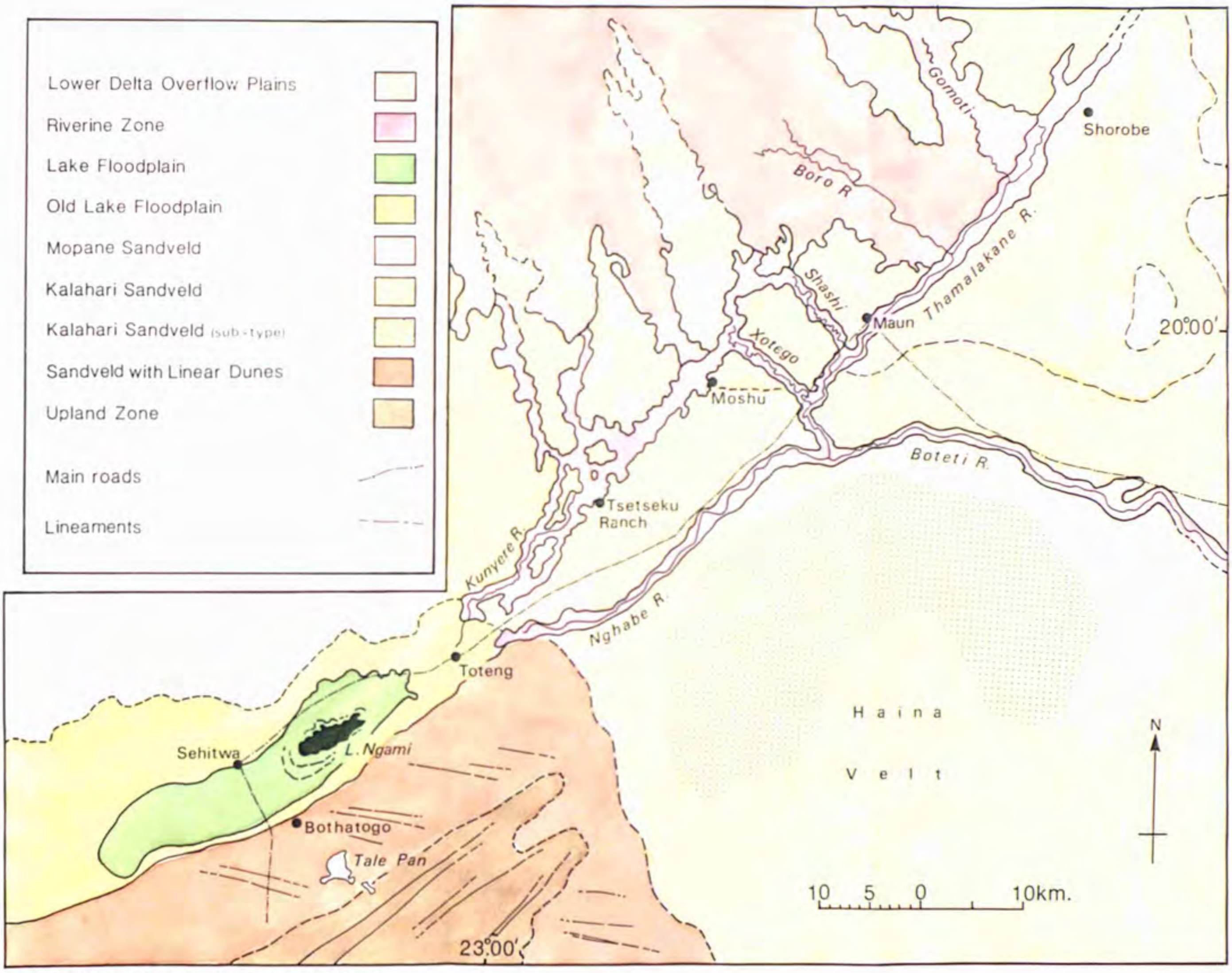


Fig. 4.4 Terrain Types (final classification).

Fig. 4.5 Floodplains and islands, Gomoti area.

Water reaches the overflow plains along a network of channels. Between Maun and Shorobe, the main channels are the Boro, Santantadibe, Gomoti and Boroyana. Flooding occurs during two annual peaks. A major peak occurs between August and September, as the waters entering the delta via the Okavango, reach the lower delta. These waters are collected in the Angolan Highlands catchment area during the previous rainy season, only reaching the lower delta at the end of the dry season. A minor peak occurs in March, when local rainfall over the delta causes a rise in water levels. Flood levels vary considerably between years. During the period 1974 - 79, high flood levels disrupted farming, water levels failing to drop sufficiently for ploughing.

This terrain type is confined at its south-western edge by the Sandvelt Tongue, a ridge of slightly higher land (a number of smaller ridges also extending into this class), and at its eastern margin, by the Thamalakane fault.The melapo west of the Kunyere fault are typical braided, broadening out towards the distal end of the delta. Patterns are detectable from the imagery, both in the melapo and islands, that suggest changes in channel flow in this area over time. Between the Thamalakane and Kunyere faults, the pattern of the melapo takes on a trellis-like form. This is probably due to the presence of old dune features which dictate the pattern of flow (orientated east-west).

Seasonal differences in ground conditions are reflected in the Landsat imagery. Imagery acquired during the peak flood period shows the extent of the melapo areas extremely well. The flooded area is seen as black on a conventional false colour image, with the fringing woodland, a bright red, typical of healthy green vegetation. However, some melapo areas may remain dry during years of low flow in the delta. For example, an image for September 1972 (fig. 4.6a), shows a large number of dry melapo during the peak period. However, after several years of higher rainfall, flooding of all the melapo between Maun and Shorobe occurred, as seen on the August 1975 image (fig. 4.6b). The difference between the lowest points of the Mazanga molapo (25 km north-east of Maun) and the tree-line is in the range of 1.5 to 2.5 metres, and a slope angle of between 0 and 3% (Staring et al., 1981).

i) Semi-aquatic vegetation in ephemeral channels and pools. The grass, Miscanthidium sp. (possibly M. teretifolium (Tinley, 1966)) and the reed, Phragmites mauritanus, occupy the central part of the floodplains, where water remains for the longest part of the year (both occupy shallow flooded sites in the perennial swamps of the upper delta (Smith, 1976)). The two species totally dominate the channels and ephemeral pools, and where these are of significant size, for example the Santantadibe channel, they can be differentiated from the rest of the floodplain as a bright red colour on Landsat imagery. The cover produced by the two species is generally very dense. The sites they occupy allow the plants to remain green and healthy throughout much of the year. Both

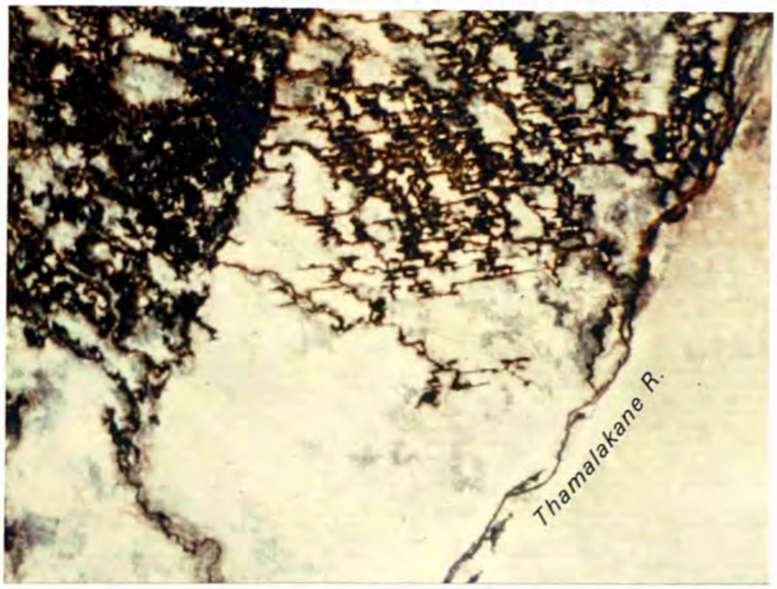


Fig. 4.6a Landsat colour composite, Maun-Gomoti area (September 1972).

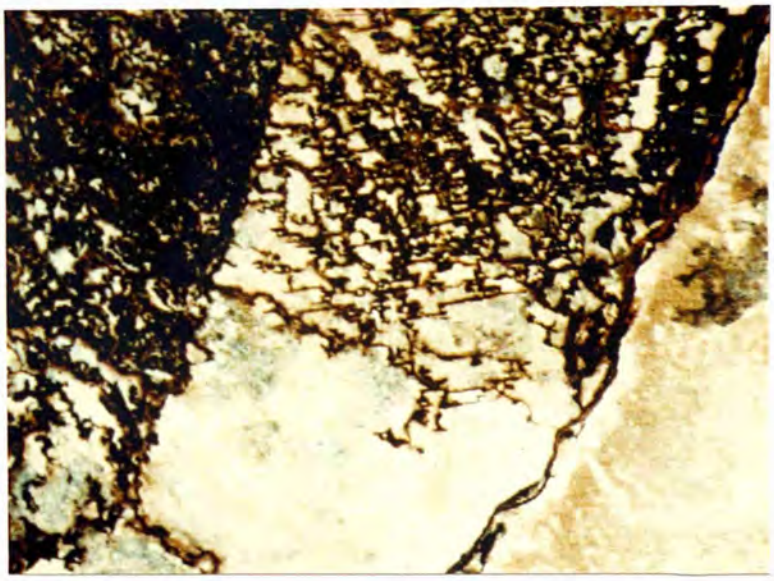


Fig. 4.6b Landsat colour composite, Maun-Gomoti area (August 1975).

Miscanthidium sp. and *P. mauritanus* are broad bladed leaved species, and together with the high density of plants, this contributes to the bright red colour seen on the composite image (high reflectance response in MSS band 7, low reflectance in MSS band 5 due to high chlorophyll absorption). The soils of this component are clayey sands, with a large amount of fine organic debris intermixed at the surface.

ii) Floodplain grassland. A number of sedges (Cyperaceae) and grasses occupy the floodplain. The dominant grass species is, *Cynodon dactylon*, which occurs throughout the floodplain. Grass cover is generally medium to dense. The soils of the floodplain vary in their clay, silt and organic matter content, across the section of the molapo. The lower parts (flooded for the longest period) are higher in clay, silt and nutrients, and are traditionally favoured for cultivation (Staring *et al*., 1981). Sandy soils are found on higher ground, which is less frequently flooded. These are often alkaline and uncultivated. In association with *C. dactylon*, the grass *Panicum repens* is found on the lower ground, and *Digitaria milanjiana* and *Eragrostis superba*, on the sandier soils. The spectral responses vary for this zone, from dark blue or green-grey near the channels to medium grey near the islands, when grass cover is lower. Soil colour is darker at lower levels (Munsell; 10YR 4/1 (dark grey)), and more reflective higher up the profile (10YR 5.5/1 (grey)). However, following flood recession, healthy green grass cover is seen as pale red or pink. The spectral responses of the vegetation is affected by the background soil reflectances, therefore the vegetation response is not as strong as for the previous component. The species are varied in terms of leaf structure, C. dactylon and D. milanjiana are relatively narrow leaved, while the other two species are broad leaved. When inundated, the melapo are seen as black, the typical response of clear water bodies.

The grassland is often burnt, to promote fresh growth, this can be seen on the imagery as dark grey-brown patches. The wind direction at the time of burning can be estimated from the shape of the burn scar.

iii) Lagoons. A few permanent bodies of water exist as lagoons, these are evident on the imagery as areas of black. The vegetation surrounding these can be classified under component (i), and is usually dominated by very dense reed beds, (P. mauritanus)(fig. 4.7). Lagoons are an important source of water for livestock in the area between Maun and Shorobe.

iv) Fringing woodland. A fringe of very dense woodland generally marks the maximum limit of flooding. The woodland contains a large number of species, importantly, Ficus sycamorous, Hyphaene ventricosa, Garcinia livingstonei, and Lonchocarpus capassa (fig. 4.8). The palm, H. ventricosa, is characteristic of this component. It grows up to about 20 m, and often occurs as an emergent above canopy level (about 10 to 15 m). The soils of this component (and the islands in general), are excessively drained fine sands with weak development of structure and horizons. These are are

Fig. 4.7 Phragmites mauritanus, lagoon near Gomoti.

Fig. 4.8 Grass covered floodplain and dense fringe woodland, Gomoti area.

classified as 'calcaric regosols' (FAO system) by Staring (1978). The woodland is very characteristically seen on the Landsat images as dark red (with some small mottles of bright red), and has a very distinct boundary with other components. This spectral response is the result of high absorption in MSS band 5 and high reflectance in MSS band 7. This is due to a number of factors; the presence of species with long, broad, rounded, generally entire leaves (leaf lengths up to 15 cm (L. capassa, F. sycamorous)), dense canopies, and vigorous chlorophyll absorption associated with relatively good moisture conditions. The woodland fringe varies in width, between 50 and 200 m.

v) Island grassland and scrub. Within the islands, the woodland gives way to sparse to medium shrub cover (1.5 to 2.5 m high) and some low scattered tree cover, the dominant species include various Acacia spp., Combretum spp., and Dichyostachys cinerea. The palm H. ventricosa is also found in shrub form. In the very centre of the larger islands, the shrubs and trees are replaced by sparse to medium grass cover (Cynodon dactylon or Sporobolus spicatus). Vegetation cover is often low, and the spectral response patterns are medium to pale blue and grey, dominated by the high reflectance of the sandy soils (Munsell; 10YR 8/1 (white), 10YR 7/2 (light grey)). Where vegetation cover increases, the tones are darker. In comparison with the fringing woodland species, the woody species found within the islands are generally small leaved, Combretum species vary from about 2 to 5 cm in length (oblong or elliptic leaves), the Acacias and D. cinerea have feathery, bipinnate leaves, each pinna having many pairs of small leaflets (in _A. tortilis_, a common species, the leaflets vary in size from 0.5 to 3 mm). The colours of the leaves are generally pale greens and grey-greens. These factors, together with lower vegetation cover than the fringe woodland and, possibly, lower photosynthetic activity due to less favourable moisture conditions, result in higher reflectances in MSS bands 4 and 5 for this component.

Colophospermum mopane is found locally, as woodland, on some of the larger islands near to the eastern margin of the terrain type. It forms small scattered patches and is not easily distinguished as separate from this component, on the imagery. Leaf shape, size and pigmentation of the dry land species differ form those associated with the floodplain fringes, and will also affect spectral responses.

vi) Pans. Rain pans occur in the centre of some of the islands, usually devoid of any vegetation, they are seen as bright white or very pale blue areas on the imagery, the result of high levels of reflectance response in all bands. A thin crust of precipitated salt may occur on some pan surfaces.

b) Riverine Zone (class 2).

This terrain type consists of the main drainage channels at the distal end of the delta (Thamalakane, Shashi, Xotego, Boteti, Kunyere and Nghabe), and associated floodplains. The Thamalakane River can be seen on the imagery in figure 4.6.

The Thamalakane and Kunyere faults reunite most of the channels of the lower delta to form the Thamalakane and Kunyere rivers. The Kunyere discharges into the Lake Ngami basin, and the Thamalakane into the Boteti River. The Thamalakane/Boteti system is supplied mainly by the Boro River (Wilson and Dincer, 1975).The Boteti is the main outflow for the delta's waters, however, it receives only some two percent (0.3 x 10^9 cubic metres per annum) of the total inflow to the delta. The Nghabe, which flows into Lake Ngami, depends on overspill from the Boteti at high flood levels. Even then water may not reach the lake.

The floodplains are gently sloping in cross section, with meandering central channels. The upper limit of normal flooding is marked by dense woodland (fig. 4.9). The rivers flow over Kalahari sands, in places encountering deposits of calcrete or silcrete. Where this happens the distinct channel form is often lost, the water flowing over the deposit, possibly creating a platform, as at Samadupi Drift. Occasionally the rivers cut through , forming small cliff-like features, for example south of Maun, where steep features about 5 to 6 m high have been formed.

The zonation of the vegetation in this unit is broadly similar to that of the overflow plains.

This terrain type is very distinct from those bordering it, in terms of the spectral response patterns.

Fig. 4.9 Thamalakane River, Maun.

i) Semi-aquatic vegetation in ephemeral channels and pools. P. mauritanus is important in this component (Miscanthidium sp.was not present at sites visited, this is confirmed by Smith (1976)), found mainly where pools form in the deeper parts of the river channels, where water is retained for the longest part of the year. The reed beds generally form very dense cover and are distinct on the Landsat imagery, as areas of very bright red. The factors contributing to the spectral responses of this component are the same as those for component i) of terrain type a). Otherwise the central channels are generally free of vegetation, the beds often consist of bare sand, with very high reflectances (10YR 7/1 (light grey)), seen as white or very pale blue on the imagery.

ii) Floodplain grassland. The floodplain grass community is similar to that for (a,ii), dominated by C.dactylon. The floodplains are heavily grazed and the rivers used as a source of water for stock; this has led to loss of vegetation cover, and to some soil erosion. The pale sandy soils (10YR 7/3 (very pale brown) to 10YR 8/1 (white)) which are exposed can be seen on the imagery as white or very pale blue patches. Bare soil was generally low, because of medium to high litter and dry grass cover, giving a medium to dark grey-blue response. The large amount of dead organic matter contributed to keeping reflectances in all bands lower than that which would have resulted from totally bare soil.

iii) Fringing woodland. This is similar in form to (a,iv), but less species rich. Species which had been sub-ordinate, now dominate, Croton megalobòtrys, Combretum imberbe, Acacia spp.. This is characteristic of drier conditions than those of the lower delta overflow plains. Several of the species found in the fringe woodland, are also found in the drier ´sandveld´ areas (Lonchocarpus nelsii, Grewia spp., Combretum imberbe, Acacia spp.). This component is seen as dark red (generally darker than that of (a,iv)). The canopy varies between 8 and 12 metres high, and cover is usually very dense. Although the proportion of small leaved species is higher in this component, a number of the dominant species are still large leaved (eg. C. megalobtrys, up to 20 cm long, ovate).

c) Lake Floodplain (class 3).

Lake Ngami is one of the terminal sinks for the waters of the delta, (the others, the Makgadikgadi and Mababi depressions, occur outside the study area). The lake is subject to widely fluctuating water levels. Inflow from the Nghabe and Kunyere channels is uncertain. The lake lies within a basin of about 220 square kilometres. The lake was formerly much greater in extent (Cooke, 1976).Evidence of ancient shorelines can be seen on the Landsat imagery. Changes in vegetation patterns indicate these features, images with high reflectances from healthy green vegetation show these features as more marked (January 1973, May 1976(fig. 4.10)). The best discrimination in a single MSS band, was from band 7. Band ratios (including 7/5), did not increase

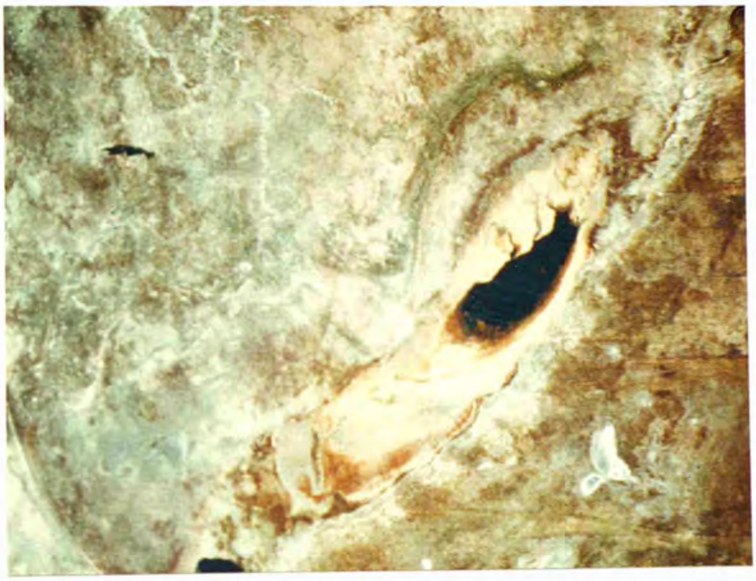


Fig. 4.10 Landsat colour composite, Lake Ngami (May 1976).

the visual discrimination of these features.

The maximum depth of the lake is about 3.5m when full (Wilson and Dincer, 1976). The lake is periodically dry, most recently in 1951, 1973-74, and 1983. The waters of the lake are easily identifiable as black, or when the lake has contracted and is shallow, as medium to dark grey-blue. In the case of the September 1972 image, density slicing (MSS band 5) of the shallow lake area provides an indication of the lake bed topography. The southern end of the lake appears to be deeper, a smaller area runs parallel to the long axis of the lake very close to its north-west edge, appearing to slope gently upwards to the southern side. Air photographs of the dry lake (1983) show a channel feature running along the latter of the deep areas, and this seems to be linked to the main inflow from the present rivers. The evidence of the Thoage system suggests that inflow was previously further south.

i) Grassland of the lake margin and supply channels. This varies with the extent of flooding, and consists mainly of the grass <u>Echinochloa</u> sp., together with (a semi-woody plant) <u>Sesbania</u> sp., at the lake margin, with species of the genera <u>Eragrostis</u> and <u>Echinochloa</u>, dominant along the channels. Peat type deposits have been found in the basin (Staring, 1978), however the soils are generally dark grey sandy loams or clays overlying light grey (non-calcareous) sands. The constantly changing margins of the lake make it difficult to delineate this component. It is visible on the imagery as a bright red fringe to the lake and area of the supply channels. The specific conditions causing the spectral response patterns evident on the various images is difficult to ascertain because of the constantly changing environment of the lake basin during the period. The bright reds seen on the composite images are certainly related to dense healthy vegetation associated with good soil moisture conditions.

ii) Floodplain grassland. The greater part of the floodplain is dominated by the grass Cynodon dactylon. A few woody species have invaded the very edge of the floodplain or dominate small, low islands at the margin. The grassland is characterised on the imagery by a smooth texture and concentric zones of varying tone around the central depression. Lower lying areas are generally darker in tone, mainly varying between medium and pale yellow-brown and blue-brown. After a period of higher rainfall, areas of the grassland appear very bright red (May 1976 (fig. 4.10)). The differences in spectral responses will be related to changes in the ratio of grass cover to bare soil and litter, and to the condition of the grass cover (varying with soil water availability).

iii) Fringing woodland and scrub. Woody species cannot survive where flooding occurs for any length of time, therefore the majority of the lake basin is devoid of trees and shrubs. With long term changes in lake levels, changes in the pattern of vegetation has occurred. Low (3 to 4 m), very dense Acacia tortillis woodland (see fig. 4.11) presently indicates the maximum lake level, on its southern side. However, recent low lake levels have allowed some re-invasion

Fig. 4.11 View from the southern scarp, Lake Ngami.

of the floodplain margin by A. tortilis shrubs (about 1 m high). If lake levels remain low, this will eventually extend the area of woodland. The dense woodland is characterised by a dark brown colour on the imagery, with very well defined boundaries. It has been noted for other semi-arid areas, that reflectance from dry highly reflective soils can be greater in the infra-red bands than for green vegetation (Allen and Richards, 1983). Where this occurs vegetation appears red only when strong chlorophyll absorption takes place. If absorption is low, the vegetation will appear darker on colour composites, as in the case of the A. tortilis woodland (and other similar situations within the study area). In 1983 the woodland was healthy and green at the time the Landsat data was collected. The soils at the margins of the floodplain are mainly dark greyish brown (10YR 4/2) silty sand. The woodland canopy is entirely of A. tortilis, with only scattered examples of the shrub Zizyphus mucronata in the understorey. The medium to sparse cover of the invading Acacia scrub, is characteristically pale brown on colour composites.

d) Old Lake Floodplain (class 4).

Associated with the Lake Ngami depression are extensive flats to the north and west of the present lake (figs. 4.4 and 4.10). It is thought that these are part either of former lake floodplain or of the Thoage floodplain, during the recent past (Staring, 1978). The unit is characterised by extensive flats with large pans, separated by sand ridges over calcrete (Staring, 1978). This area no longer receives water from the delta, but ponding of rainwater is common.

Much of the water once reaching Lake Ngami, was by way of the Thoage system, to the north. This, however, became choked with papyrus and the waters diverted to the east. The redundant channel systems can still be clearly seen on the imagery, these are seen as lighter tones (pale blue-grey), than the surrounding low tree and shrub savanna. This indicates low vegetation cover in the old channels, possibly the result of differences in the edaphic conditions.

A number of larger settlements are found in this type, including Sehitwa and Toteng. These are characteristically surrounded by a zone of heavily grazed land, bare soil surface is often high to very high, producing high reflectance in all MSS bands.

i) Low tree and shrub savanna. The extensive areas of flats are characterised by scattered low trees and shrubs. The dominant genus is Acacia, with a number of species present (A. erubescens, A. mellifera, A. tortillis). Grewia spp. are also common in the shrub layer. Dichrostachys cinerea is found in association, particularly near disturbed ground. Near Toteng, Terminalia prunioides occurs as scattered trees. Terminalia sericea is locally dominant on small sand ridges. The vegetation cover varies between sparse and medium, with dense localised patches The soils generally sandy (10YR 7/1 (light grey) to 10YR 6/3 (pale brown)). The spectral responses vary from dark to medium blue-grey and purple-grey. Variation in tone and colour is mainly a product of the proportion of vegetation cover against amount of bare soil. This will be modified by a number of other factors; for example,leaf shape, colour and condition of the dominant species. The Acacias are characteristically small leaved, and often pale green or grey-green in colour.

ii) Redundant channels and associated vegetation. The channels of the Thoage system form a pattern similar to those of the lower delta overflow plains (a). However, these are now redundant and the vegetation is dominated by species typical of drier conditions. The old channel courses are dominated by scattered low trees and shrubs, mainly Acacia species. Acacia erioloba is commonly found and is indicative of old water courses and levels in this area (Timberlake, 1980; Cole, pers. comm.). The sparse ground cover is dominated by C. dactylon. The soils are generally fine sandy loams, associated with quiet sedimentation conditions (Staring, 1978). The redundant channels are clearly visible on the imagery, characteristically much lighter in tone (light blue-grey to white) than the surrounding low tree and shrub savanna, an probably the result of lower vegetation cover.

iii) Pans and associated vegetation. Small rain pans are found throughout this terrain type, formed by the ponding of rain in natural depressions during the summer, these form a focus for both wildlife and livestock. The combination of waterlogging for part of the year, heavy trampling and grazing, leads to low vegetation cover and soil erosion. A few scattered trees and shrubs often surround the pans, mainly Acacia species. The pans are generally sandy at the margins, and often have clay deposited at the centre. When the clay is dry, it often cracks forming small smooth, concave flakes, dark in colour (5Y 4/2 (olive green), and highly reflective. The pans are seen on the imagery as small, white to very pale blue features, oval in shape.

iv) Southern escarpment. Along the southern margin of Lake Ngami, a minor scarp (see fig. 4.11) separates the floodplain (c), from terrain type (f). This feature probably represents the southern limit of the once larger lake, no evidence of shoreline features south of this are evident from the Landsat imagery or air photography. It has been suggested that several of the large pans south of the scarp were initially formed as a result of overflow from the lake (Buerger, 1976), which would have involved water overtopping the escarpment. The slope is concave, gently sloping at the base and steepening near the crest. Near the village of Bothatogo, the scarp is accentuated by outcropping rocks of the Karoo sediments. The gentle slope at the base of the scarp is characterised by scattered to medium tree cover, and very few shrubs. Grass cover is very sparse, due to heavy grazing pressure around a number of wells, which follow the line of the escarpment. The dominant tree species is A. tortilis, between 2 and 4 metres in height. Associated species include, A. mellifera, A. erubescens and Zizyphus mucronata. The soils are fine sandy to silty sands in texture, and greyish brown (10YR 5/2) to dark greyish brown (10YR 4/2) in colour. As the slope steepens, especially where there is some outcropping of the country rock, the vegetation is generally shorter and more open, with shrubs (D. cinerea, Boscia foetida) becoming more common. The soil is the very similar to the lighter, sandier soils of the lower slope. The is soil is very highly exposed over the whole of this component, with very low litter cover. This component is seen on the imagery as mottled, pale to dark blue-grey, the large expanses of bare soil dominating the response. The darker tones are caused by areas of denser vegetation.

e) Mopane Sandveld (class 5).

The Mopane sandveld is part of the level to gently undulating Kalahari Plateau (1,000 to 900 m above sea level). There is no seasonal flooding in this terrain type. Throughout the Mopane sandveld, layers of impervious calcrete create the conditions needed for ponding of rainwater. The rain pans formed provide water for both cattle and wildlife. Small pans are often found at intervals along depressions between sand ridges.

The Mopane sandveld is generally level to gently undulating, with sand ridges forming gentle rises and swales. Examination of aerial photographs suggest an east-west trend to these ridges. The line of the ridges is broken and eroded in many places, but from the air photographs it can be seen to resemble other (well preserved) dune fields, to the south of Lake Ngami, and extensive areas to the north and west of the delta (clearly visible on Landsat imagery). The ridges can be seen to have once formed parallel dunes, this has been more clearly detected in the ´melapo´ area near Shorobe (a, above), which appear to be a continuation of ridges between the Kunyere and Thamalakane faults.

The soils of this terrain type are characteristically aeolian deposits, often excessively drained, fine Kalahari sands, typically pale in colour. Soil structure is poorly developed, and horizons ill-defined (Staring, 1978). The aeolian deposits appear to overlay alluvial deposits over some of the area (Staring, 1978).

This terrain type is dominated throughout by a single tree and shrub species, Colophospermum mopane. C. mopane is an 'aggressive' species, and appears to be extending it s range into areas characterised by other forms of savanna vegetation in Southern Africa (Cole, 1982a). The occurrence of C. mopane in the Okavango Delta area appears to represent an 'outlier' of the main zone of C. mopane tree and shrubland of north eastern Botswana (Field, 1978). The Okavango area is regarded by Cole (1982a) as a 'vegetation tension zone' (see section 3.4). C. mopane often exists in almost pure stands. The main area of Mopane Sandveld is to the north of the Boteti River (see figs. 4.3 and 4.4).

i) Sand ridges and elevations with Colphospermum mopane woodland. C. mopane woodland is generally associated with higher ground, shrub savanna with depressions and low plains. The woodland canopy cover is generally sparse to medium, and is totally dominated by C. mopane. The canopy varies between 6 and 12 m in height. The understorey is dominated by young C. mopane and a number of associated shrubs (Ximenia americana, Grewia flavescens, Lonchocarpus capassa). The soils are composed of fine sands, grey (10YR 5/1) to greyish brown (10YR 5/2) in colour (C. mopane is found on a variety of soil types (Palmer, 1977), to the north of Maun, in the Moremi and Chief's Island areas, it is associated with grey clay-pan soils (Tinley, 1966; Biggs, 1976)). The area of exposed soil is generally high, with a low grass and litter cover.

The spectral response of the woodland areas varies from dark orange-brown, where localised areas of dense woodland are found (north-east of Maun), to medium orange-brown and red-grey, over most of its distribution. The leaves of C. mopane are very distinctive, formed of two leaflets hinged together at the base, which fold together in dry weather (Van Voorthuizen, 1976). The leaves are bright green after the summer rains, turning a conspicuous yellow-brown during the period July-August (C. mopane is deciduous). On the September 1972 imagery, the woodland near Moshu is seen as dark grey-blue on the colour composite, while it is still orange-red in August 1975.

ii) Minor plains and depressions, with Colophospermum mopane shrub savanna. The shrub savanna canopy cover is also sparse to medium, and is often totally devoid of any trees. The general height of the shrub layer is 1 to 1.5 m. The shrub layer is almost pure C. mopane in most cases, with only scattered individuals of other species (Grewia flavescens, Acacia spp.). The soils are fine to loamy sands, light grey (10YR 7/1) to grey (10YR 5/1) in colour. The area of exposed soil is high, with low grass and litter cover. The shrub savanna is generally similar in colour on the colour composites to the woodland, but of paler tones. Where there is a distinct boundary between the woodland and shrub (see fig. 6.2), this can be clearly seen on certain dates of Landsat imagery. A number of possible causes exist which may produce distinct reflectances from the woodland and shrub areas. These include such factors as canopy structure, differences in leaf pigmentation or associated species (see chapter VI). For example, the leaves of C. mopane change to a characteristic yellow and orange brown during the dry season, but often remain on the tree for much of the winter (Tinley, 1966). It has been observed that shrub areas often have a redder hue than the trees (Prince, pers. com.), this could provide one explanation for differences in the reflectance characteristics of the two vegetation types.

There are a number of possible explanations for the existence of the distinct mosaic of woodland and shrub that occurs within this terrain type. Tinley (1966), working in the Moremi area, attributes the formation of the shrub areas to fire ('pyrophytic shrub savanna'), where the "...tree growth form is changed to shrub or scrub growth: typically, multi-stemmed coppices are produced from the charred original stem." Cole (1982a) notes that the stature of individual plants is markedly lower along drainage lines, where cold air accumulates on winter nights, and that there is evidence to suggest C. mopane is sensitive to low temperatures. This explanation would fit the pattern of shrub and woodland related to topography, that is found in the study area. However, the sharp cut-off between the components that is often found, and the coppice form of the shrubs, might argue for a combination of these factors. Tinley (1966) believes that frost action may be a factor, in maintaining the shrub form once it has been produced by fire, he quotes Keet (1950), who notes "...suckers and coppice shoots are more sensitive to the effect of frost, drought and fire than seedlings of the same age or size; the repeated damage by these agents reduces forest or woodland to useless scrub and seldom to useful grassland.". If the shrub form is more sensitive to cold, this would account for the fact that the shrubs turn yellow much earlier than the trees, especially where these occupy the cooler depressions between the warmer wooded ridges.

The pattern of woodland and shrub varies over the Mopane sandveld, where sand ridges and depressions are more accentuated (eg. the Moshu area), the boundaries between them are very clear, however, where these are less distinct, there is often a continuum from woodland, through low tree and shrub savanna to pure shrub.

iii) Pans. The description of this component is the same as for d) iii). The pans tend to occupy the lowest parts of depressions and plains.

f) Kalahari Sandveld.

The Kalahari sandveld is also part of the Kalahari Plateau, and is similar in terms of topography to the Mopane sandveld. However, rain pans appear to be more frequent in this terrain type.

The Kalahari sandveld is characterised by aeolian deposits. The soils are excessively drained, fine Kalahari sands, with a typically pale grey or brown colour (fig. 4.12). Structure is poorly developed and horizons are ill-defined. The aeolian sands are predominantly quartz, with low concentrations of clay forming minerals (Staring, 1978). Figure 4.13 shows the main areas of Kalahari Sandveld between the Thamalakane and Kunyere faults, and the Haina Veld.

i) Sand ridges with low tree and shrub savanna. Parallel groups of sand ridges form a landscape of gentle rises and intervening swales. The wave length between ridge crests at Tsetseku ranch, varied between about 300 and 450 metres, with only a rise of 2 to 3 metres from the ´trough´ to the crest (section 5.7.1). The tops of the ridges are often form level ground for 100 metres or more before descending into the next depression. The vegetation of the ridges´ is generally dominated by low trees with some scattered shrubs. The tree cover varies from medium to dense, with localised patches of very dense cover. The dominant tree species and density of cover vary over the ridges, seeming to correspond to slight changes in topography. The level tops of the ridges are often dominated by medium to dense shrub cover with scattered trees (see fig. 5.4b). The dominant shrubs are Grewia bicolor and G. flava. The associated tree cover is dominated by various Acacia species. A number of other trees and shrubs are locally dominant, for example D. cinerea, which forms dense thickets, often on the sites of abandoned kraals. Terminalia sericea is locally dominant, often to the point of forming

Fig. 4.12 Typical soil surface, Tsetseku Ranch.

monospecific stands (see fig. 5.4c). *Lochocarpus nelsii* is usually associated, but in small numbers. At Tsetseku, *T. sericea* is usually found to dominate the upper slopes to the crest, but tends gives way to *Acacia* and *Grewia* spp. on any level terrain. *T. sericea* appears to be associated with deep, loose sand. A number of grasses were identified at Tsetseku ranch, however, due to the poor condition generally, of grasses at this time, it is not possible to give a detailed description of their distribution over the whole of the sandveld. The species identified were found in both component i) and ii). The grass cover includes, *Aristida congesta* , *Tragus racemosus*, and *Urochloa mosambicensis*, indicative of disturbed ground and overgrazing. The soils are of loose to slightly compacted sand, light grey (10YR 7/2) to light brownish grey (2.5Y 6/2) in colour. Litter cover is generally low.

This component is darker in tone than the others in this terrain type. On the conventional colour composite, it varies between dark grey-blue to grey (September, 1972) to dark to medium reddish-grey and reddish-brown (August, 1975). The red hues are probably indicative of strong chlorophyll from both woody and grass cover after a period of good rainfall. The dark grey and blue-grey was probably the result of low reflectances in all MSS bands due to non-green woody vegetation masking stronger reflectances from the soil.

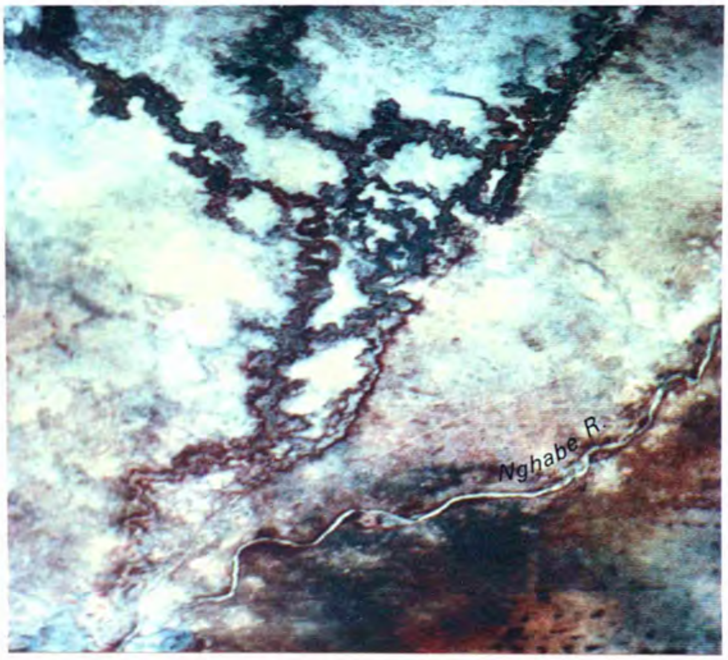


Fig. 4.13 Landsat colour composite, Nghabe River area (May 1983).

ii) Minor plains and depressions, with low tree and shrub savanna. The plains and depressions lie between the sand ridges. Where the line of the sand ridges is undisturbed and lie close together, linear sets of depressions are found. Where the sand ridges are less distinct, small plains of variable size and shape occur, with rises of higher ground in places, the remains of sand ridges. The dominant vegetation cover is sparse to medium low tree and shrub savanna (see fig. 5.4a). Acacia species dominate the scattered tree component (A. tortilis, A. mellifera, A. erubescens), with the shrub layer dominated by Grewia bicolor and G. flava, and Acacia shrubs. Other shrubs typical of this component include, Rhus tenuinerus, Dichrostachys cineria (which locally may be dominant). The soils are fine sand, often compact especially near to the centres of depressions and pans, and are very pale, light grey (10YR 7/1) to white (10YR 8/1). Litter cover is generally very low and exposed soil high to very high.

Like component i), this component varies markedly in its spectral response between good and bad rainfall periods. It varies from pale grey and grey-blue (September, 1972), to pale reddish-brown and pink (August, 1975) possibly following a flush of growth of the herbaceous layer. On most of the images this component is characterised by pale tones of grey and blue-grey, indicating strong soil reflectivity in all bands, and a weak response from the sparse vegetation.

iii) Pans. The description for this component is the same as for d) iii). The pans are often found at intervals along depressions. The frequency of occurrence varies over the Kalahari sandveld zone, more common where sand ridges and depressions form gently undulating ground, for example between the Kunyere and Thamalakane fault lines, south of Maun.

f) Kalahari Sandveld - sub-type (class 7).

this sub-type is characterised by the occurrence of dense patches of Terminalia prunioides woodland, which forms a distinctive component on the Landsat imagery (fig. 4.14). This component does not occur throughout the rest of the Kalahari sandveld type. In all other ways this sub-type appears to conform to the characteristics of the Kalahari sandveld terrain type.

Terminalia prunioides has a very scattered distribution over most of the sandveld. It is found as single, scattered trees at Tsetseku, within the areas dominated by Acacia and Grewia low tree and shrub savanna. It is also reported to grow in sandveld country of the Moremi area, to the north of the study area (Tinley, 1966). Only to the south of the Boteti River, in the Haina Veld, does it occur as the dominant woodland tree. The T. prunioides woodland appears to occupy slight rises in the relief, and the pattern of woodland areas, as seen from air photography and Landsat imagery, suggests it is related to the old dune systems of east-west orientation. The pattern is interrupted, with scattered 'islands' of the woodland separated by sandveld dominated by the typical Acacia

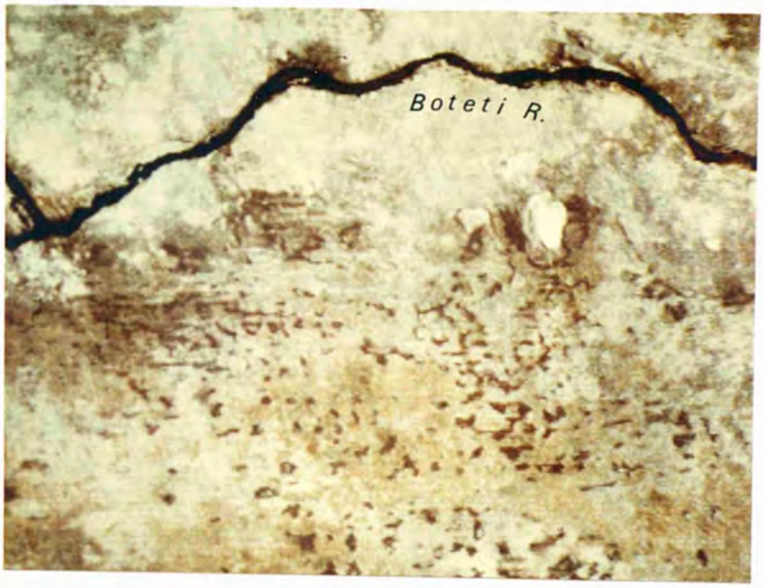


Fig. 4.14 Landsat colour composite, Haina Veld (August 1975).

and Grewia low tree and shrub savanna. The woodland canopy is generally of medium to dense cover.

The woodland areas are distinct on the Landsat imagery, as dark brown areas, often ellipsoid in shape (the long axis orientated east-west). The leaves of T. prunioides are small (less than 5 cm long), and smooth, forming tufts at the ends of branches.

Evidence from Landsat imagery, suggests the woodland is limited to the Haina Veld. A boundary between the sub-type and the main terrain type f), cannot be easily distinguished on the basis of the single distinctive terrain component.

g) Sandveld with Linear Dunes.

This unit is broadly similar to the sandvelt described above, but is dominated by large linear dunes. These are no longer active, having been stabilised by vegetation. The dunes have an east-west orientation, and form a distinctive undulating terrain. This terrain type is covered largely by the sands of the Kalahari beds (Tertiary to Recent in age). These beds overlie rocks of the Ghanzi formation and of the Karroo sediments (Buerger, 1976; Hutchins et al., 1976). A number of large pans form one of the main components of the terrain type (Tale, Talenyane and Nwaku)(fig. 4.15), as well as numerous smaller pans.

i) Major sand ridges with low tree and shrub savanna. In this component, the sand ridges are formed by the stabilisation (by vegetation cover) of old dune features.

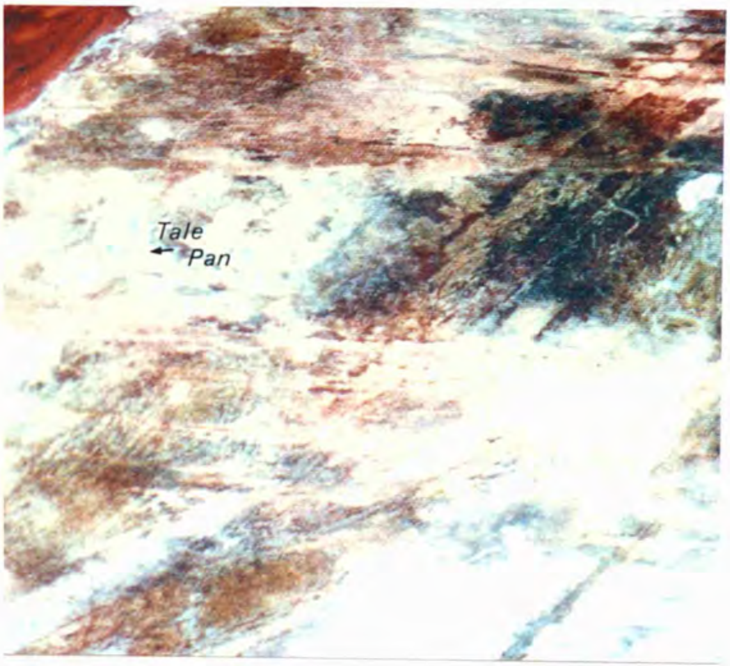


Fig. 4.15 Landsat colour composite, Tale pan - Kgwebe Hills area (May 1983).

These are well preserved and generally uninterrupted features, crossing the terrain type (east-west). They are between 500 and 800 m wide, and up to tens of kilometres long. These are much larger scale features than those associated with the Sandveld and the Lower Delta Overflow Plains, but are probably related. Extensive areas of the ridges are dominated by Terminalia sericea low tree and shrub savanna (with Lonchocarpus nelsii in association). The canopy is generally dense, and between 2 and 3 m in height. Other woody species (Acacia spp., D. cinerea, G. bicolor), are found as shrubs and scattered trees, especially near the boundary with other components. The soil is generally deep, loose sand, of fine texture, reddish brown (5YR 5/3) to pale brown (10YR 6/3) in colour (fig. 4.16)

This component is clearly defined on the Landsat imagery, with a distinct boundary between itself and other components (the boundary is also distinct on air photographs), and is seen as reddish-brown to pale red or pink-grey. It appears to have higher values in MSS bands 6 and 7 than other areas of dense woody cover, but similar values in MSS band 5, the chlorophyll absorption band. The leaves of T. sericea are silvery-grey (thickly silky to hairy with age (Palmer, 1977)), this probably contributes to high reflectances in the near infra-red wave lengths.

ii) Depressions and plains with low tree and shrub savanna. Between the large sand ridges are depressions, varying in size from less than a kilometre to several kilometres in width. In places the ridges are absent and

Fig. 4.16 Terminalia sericea dominated vegetation near Tale Pan.

small areas of level to gently undulating terrain occur, for example to the west of Tale Pan. Tale Pan may have been initiated by overflow from Lake Ngami, if this occurred after the formation of the dune system, this could account for the absence of ridges in this area, and their presence to the north, south and east.

The vegetation of this component is similar to that of the Sandveld to the north. The low tree and shrub savanna cover vary from scattered to dense in places, with a general canopy height of between 1 and 2 metres. A form of low tree savanna with a less dominant shrub element occurs in places. The dominant species in this component are Acacias (A. tortilis, A. mellifera, A. erubescens) with Grewia bicolor and Boscia foetida as co-dominants over parts of the area. Associated species include D. cinerea (shrub), Combretum sp. (tree and shrub), and T. prunioides (tree). The grasses Aristida hordeacea, A. scabrivalis and Cenchrus cilliaris are commonly found in this component (Buerger, 1976). The sandy soils of this component vary in colour between light grey (10YR 7/2), brown (10YR 4.5/5) and yellowish brown (10YR 5/6) in colour.

The spectral response patterns of this component are well defined at their boundaries with component i), but less distinct at boundaries with component iii). This reflects the fact that there is an ecocline between the low tree and shrub savanna and the pan fringing woodland, rather than a distinct boundary, this ecocline is seen on the ground as both compositional and structural. The colour of this component varies from pale yellowish-brown to pale or medium brownish-grey. The yellowish colours seem to be related to the areas of yellowish-brown soils, with lower MSS band 4 values, while the grey colours are related to the light grey and light brown soils with high values from the soil in all bands (tone being dictated by vegetation cover). The species composition between these areas remains broadly similar, with very slight differences in the dominant Acacias and their co-dominants. For example a pale yellowish-brown area (image of 19 January 1973), had a cover of scattered trees and shrubs, dominated by A. tortilis and B. foetida, with G. bicolor, Combretum sp., and T. prunioides in association, on yellowish brown soil (10YR 5/6), while a pale brownish-blue/grey area, with the same cover characteristics and dominated by A. tortilis and A. mellifera, with Combretum sp., D. cinerea and T. prunioides in association, is found on greyish brown (10YR 5/2) to brown (10YR 4.5/3) soil.

iii) Pans. Pans form an important component of this terrain type, they range in size from a few hundred metres wide to over 1.5 kilometres in the case of Tale pan. The small pans are probably formed as a result of rain flow into small natural depressions, which then become the focus for animals seeking water. The pressure on the vegetation around the rain pan then leaves the soil unprotected from deflation by wind action during the dry season, this will serve to accentuate and extend the depression. Buerger (1976) thinks the larger pans, such as Tale, Talenyane (fig. 4.17) and Nwaku, may have originally formed as a result of overflow from Lake Ngami.

Fig. 4.17 Tale Pan.

The depressions becoming established as pans due to alternate deflation in dry periods and flooding from lake overspill. Wave action during periods of inundation may have formed the small undercut cliffs found around the Tale and Talenyane pans. The Tale pan complex is the largest in this component (over 6 square kilometres), the main pan appears to be fed with rainwater by a number of drainage features to the east, the smaller Talenyane, is fed from the south-east. These drainage features appear to be partly controlled by the east-west orientation of the ridges and depressions. There is no evidence from Landsat or air photographs, of any recent drainage from immediately north or west of the pan complex.

The pans are totally lacking trees or shrubs, except at the extreme margins (fig. 4.17), where some invasion has taken place during the years of lower rainfall and hence lower flood levels in the pans. A fringe of trees and shrubs usually indicates the maximum level of flooding. The pans generally have a cover of savanna grassland, the aerial cover varies from very high, after rains, to low, at drier periods, at the pans margins, while centrally the cover is usually low to absent. The grassland is characterised by Enneopogon brachystachus, Sporobolus spicatus and Oropetium capense, with a scattering of suffructicose vegetation (Leucosphaerea bainesii and Plinthus karrooicus) (Buerger, 1976). The soils vary from olive grey (5Y 4/2) sandy clays, centrally (often with patches of salt precipitate, (7.5YR N8/0)), to light grey (7.5YR 7/0) to white (10YR 8/1) compact sandy soils towards the pan margins.

The boundaries of this component are very clear from the Landsat imagery. The majority of the smaller pans and the outer parts of the larger pans, are characteristically white to very pale blue, the result of very high reflectances in all wave bands, related generally to high amounts of exposed soil. Centrally, the pans are greyish to purplish-blue, the darker sandy clay material being less reflective than the pale sandy soils of the outer pan.

iv) Pan fringing woodland and related features.
Surrounding the pans is often a dense to very dense fringe of low savanna woodland (fig. 4.17), grading into low tree and shrub savanna away from the pans. This component is dominated by two Acacia species, A. mellifera (associated with calcium-rich soils at the edges of pans, depressions and calcrete outcrops, (Field, 1976)), and A. tortillis. Associated species include, A. erubescens, Combretum sp., Grewia bicolor, and T. prunioides, with scattered B. foetida, D. cinerea and T. sericea. Buerger (1976) describes localised stands of the shrub Catophractis alexandrii as indicative of near surface calcrete in this area. Calcrete is exposed at the pan margins in a number of places, for example at Tale pan, where small cliff features are found. Some pans have slowly been colonised by woody vegetation and are slowly reverting to low tree and shrub savanna, the characteristic fringe of woodland remains as evidence of their existence, and can be seen clearly on air photographs and to some extent on the Landsat imagery. The soils are sandy, varying in colour from brown (10YR 5/3) to light brownish grey (10YR 6/2.5).

This component is characteristically dark brown on the imagery (see terrain type c) component iii).

h) Upland Zone.

This terrain type was not surveyed in any detail during the 1983 field survey. Description of the ground characteristics are based on the work of Buerger (1976) and Cole (pers. comm.).

Outcrops of the Kgwebe formation (quartz-feldspar porphyry and diabase (Hutchins et al., 1975)), form the high ground of the Kgwebe Hills south east of Lake Ngami. The majority of the formation is, however, covered by Kalahari sands, forming a rolling to undulating upland topography. Although the underlying geology is buried, evidence of its structure is evident from Landsat imagery, the general trend is north east - south west. This is is probably related to changes in vegetation cover, Cole (1982b) describes a similar situation at the Ngwenalekau Hills to the south of the Kgwebe Hills, where "...despite the cover of Kalahari sand and calcrete, the Proterozoic sedimentary sequence that hosts the copper deposit can be delineated ...distinctive spectral reflectances discriminate between the vegetation over the copper deposit and that over adjacent barren bedrock.". Sand ridges, characteristic of the Sandveld to the west, extend into this terrain type, seen superimposed over the patterns related to the underlying geological structure, on the Landsat imagery (fig. 4.15).

i) Kgwebe Hills, low tree and shrub savanna. The hills are in the form of relic inselbergs, with a vegetation cover of low tree and shrub savanna, dominated by Combretum apiculatum and the shrub G. bicolor. Associated species include, A. erubescens, Commiphora pyracanthoides and Markhania acuminata. The prevailing grass species is Eragrostis superba, with Stipagrostis uniplumis where patches of deep sand cover have accumulated. The soils formed over the quartz porphyry are reddish brown (5YR 4/4, moist) in colour. Cole (pers. comm.) notes the presence of a tree of the genus Kirkia, as indicative of quartz porphyry outcrops in this area.

The hills are detectable on the imagery as marked relief features from the effect of the reflectance patterns caused by shadows. The red soil gives the imagery a distinctive dark green colour, due to high reflectance in MSS band 5.

ii) Upland low tree and shrub savanna. The rolling to undulating topography is has a cover of trees and shrubs characterised by A. mellifera, A. Karoo and A. nebrownii, Catophractis alexandri and D. cinerea. Stipagrostis uniplumis is the dominant grass species.

The colour on the imagery varies from dark (grey) green, to dark blue, to pale grey. The green colours may be related to reddish soil derived from the underlying rock.

iii) Sand ridge with low tree and shrub savanna. These are an extension of terrain type f) i), into this terrain type, the description is the same.

4.9 Discussion of the use of Landsat MSS data for terrain analysis.

4.9.1 Introduction.

The use of Landsat MSS data for mapping and classification of natural terrain is seen to have a number of advantages over conventional methods involving the use of aerial photography and/or ground survey. However, certain limitations were apparent, in particular with regard to the use of computer aided classification procedures.

4.9.2 Advantages of Landsat MSS data.

Landsat data can provide a synoptic view of a large target area (a single scene is approximately 185 km x 185 km). The digital format in which the individual scene elements (pixels) are recorded, means direct comparisons of reflectance levels can be made between any two individual pixels over the whole scene. This avoids the the problems associated with comparison of particular features on aerial photographs, where tones (and colours) often vary between individual photographs, as well as problems of joining photographs together to make mosaics. If two or more Landsat scenes are used, computer programs are available for 'merging' the digital data sets. Landsat data can also be digitally corrected to fit various map grids where appropriate, using available 'geometric correction' programs.

Landsat imagery can be reproduced at a variety of scales within the limits of the data resolution. This allows ease of comparison with other forms of data. At a certain point, due to the size of the individual pixels, it will become inappropriate to further enlarge the scale of the imagery. However, the resolution was fine enough to allow comparison with 1:50 000 aerial photographs during this study.

By recording variations in response of ground features to selected parts of the electromagnetic spectrum, the Landsat system provides the opportunity for greater discrimination of these features from one another, than conventional aerial photography. The digital format of the data allows a wide range of combinations of band values to be used (for colour composites, band ratios, Principal Components Analysis and other mathematical options) and enhancements of the resultant images to be made. This capability provides the opportunity to test new methods of terrain analysis, based on spectral response patterns, as opposed to the conventional use of topography as the main definitive characteristic used in the land systems approach. In the case of the present study, the use of vegetation patterns (mapped from spectral response patterns) provided the major definitive characteristic for terrain analysis.

The frequency of data availability from Landsat is high (the satellite passes the same position on the earth's surface once every 18 days), when in range of a ground receiving station. Aerial photographic surveys within individual countries are generally much less frequent, especially in

´developing nations´ such as Botswana (since the launch of the first Landsat satellite in 1972, the whole of the present study area has been photographed twice, while parts of it were included in two other surveys). The frequency of Landsat data availability provides the opportunity to build a multitemporal data set, covering a range of ground conditions (seasonally, and between years). Multitemporal data sets facilitate long term monitoring of environmental change in natural terrain.

The cost benefit of using Landsat data against other forms is difficult to calculate. The cost will depend upon a number of factors, both environmental and logistical. For example, access within the target area for other forms of survey or data gathering connected to a Landsat based survey, the expertise and availability of staff involved in survey and data processing/analysis, the type of data processing systems available. The cost of the raw Landsat data is presently low, relative to aerial surveys, however, if the system should become a commercial concern (as opposed to its present experimental status), this situation may change. This would be especially critical for ´developing countries´ (Mackenzie, 1984).

4.9.3 Constraints on the use of Landsat MSS data.

Landsat data cannot be used in isolation, other forms of data are essential for verification of satellite image interpretation. This can be in the form of ground survey, aerial photography and published material, especially maps. Of these, ground data is probably the most important and reliability of the data will strongly affect the interpretation of the satellite data and the interpolation of the results into areas not covered in the field (Justice and Townshend, 1981a). Field experience is also likely to increase the accuracy of data interpretation, Gisladottir (1983) has shown this in the case of aerial photograph interpretation, and he considers field experience essential for image interpretation.

Difficulties arise in the use of Landsat data if separation of terrain features is simply based on differences in reflectance levels, even when multiple band data is used. This is especially a problem associated with the use of computer aided classification procedures. These procedures are unable to distinguish between different ground features on the basis of texture, shape, relative size and position of image features. This means that at present, visual classification, using similar techniques to that of conventional aerial photographic analysis, is essential to the analysis of natural terrain. The computer aided classifications may be useful in provisional analysis of the data prior to detailed visual interpretation and classification.

V. Mapping Woody Vegetation using Landsat MSS Data: A Potential Range Management Tool.

5.1 Introduction.

Early research into the use of multispectral satellite data for rangeland resource evaluation was mainly carried out in north America. The work focused primarily on herbaceous layer vegetation (principally grasses) and tried to develop methods of measuring such factors as the standing biomass (Pearson and Miller, 1972; Carneggie *et al*., 1975; Haas *et al*., 1975; Seevers et al., 1975). Recent research in Africa has tended to follow this pattern (Lane, 1972; Griffiths and Collins, 1983; van Gils and van Wijngaarden, 1983) or concentrated on more general surveys of total vegetation cover (Mitchell, 1981; Allen and Richards, 1983; Vass, 1983). The woody component (trees and shrubs), in terms of it´s role in rangeland use and management, has largely been ignored in remote sensing studies. Some measurement of woody cover has been included in studies, in order to be able to remove it´s contribution to the total vegetation (Lane, 1982). However, tree and shrub species form an important component of of the vegetation in many areas of semi-arid rangeland in Africa. The effect of woody vegetation on range quality has both negative and positive characteristics. For example, encroachment of undesirable woody vegetation into areas of grassland savanna is regarded as a problem over much of Africa; Kowal and Kassan (1978), note a natural tendency for savanna grassland (in west Africa) to be invaded by woody species. Van Rensburg (1971a) describes encroachment as one of the major problems of grassland deterioration in southern Africa. However certain woody species may be beneficial to range quality, providing browse and shade.

5.2 The importance of woody vegetation in savanna rangeland.

5.2.1 Bush encroachment.

Bush encroachment is often associated with increases in stocking rate, hence grazing pressure (Field, 1978), "Defoliation of the grasses greatly reduces their root activity, especially with regard to growth and water absorption. Under a grazing regime, therefore, the competition between plants for the limited amount of available soil moisture swings in favour of the little grazed or ungrazed woody plants." (Martin, 1971). Invading woody vegetation also competes for valuable space and nutrients, as well as moisture. In Botswana, invading species are often poor in terms of browse value, for example Acacia tortilis, A. mellifera and A. fleckii (Timberlake, 1980).

There is evidence to suggest that increased woody cover leads to a decrease in grass cover. Donaldson and Kelk (1973) claim that in the Molapo area of Cape Province (South Africa), yields of hay from pasture with 1071 bushes per hectare was only 10% of yields from pasture with no bushes. Van Rensburg (1971b), working in Botswana, observed that where bush cover was 34%, associated bare trampled ground was 30%, in comparison with woodland with 2.5% bush cover and 2.5%

associated bare ground. Sandford (1983) compares two situations in east Africa, the bush dominated Tsavo National Park, Kenya, where only 18% of net above ground primary production was consumed by mammals, even in drought periods and a similar area of grass dominated pasture, where sustained yields of between 50 and 70% of net primary production occurred.

However, other studies, while confirming a negative relationship between grass cover and woody cover, indicate the relationship may be a weak one. The Animal Production Research Unit (APRU) Botswana, collected data from 20 ranches across the country (including Tsetseku, in Ngamiland), which indicated that for every additional 72 trees or shrubs per hectare basal cover of grasses decreased by 1% (APRU, 1975). The correlation coefficient for the regression was low, $r = -0.44$. Lane (1981) working in Tanzanian semi-arid rangeland, with variable tree and shrub cover types, also found weak negative correlation between amounts of grass and woody cover (semi-deciduous woodland, $r = -0.17$; deciduous bushland, $r = -0.28$; thorn shrubland, $r = -0.56$). Griffiths and Collins (1983), found as similar relationship for semi-arid rangeland in Kenya ($r = -0.54$).

5.2.2 Browse.

Some woody species can provide valuable browse for livestock and wildlife, for example, certain Acacias (Leguminosae) are often rich in proteins and nitrogen, the pods of <u>A. erioloba</u> are gathered and fed to cattle in Botswana during dry periods (Timberlake, 1980). Members of the genus Grewia, also regarded as useful browse, were recorded at 18 of 20 ranches in Botswana (APRU, 1975). Deep rooted species may remain green during dry periods, providing fodder for livestock. Field observations (APRU, 1980) indicate that cattle prefer grass to browse, resorting to this only when grass is unavailable, therefore, where browse species are in competition with grasses, they may be regarded as undesirable.

5.2.3 Shade.

Timberlake (1980) stresses the importance of shade trees for livestock, however, there is no evidence from Botswana (APRU, 1980) to indicate that cattle performance differs between those with shade available and those without.

5.2.4 Other uses.

Woody plants are also important throughout the rangeland areas of Africa as a source of fuel (Nichol, 1983) and building materials for the local populations, including pastoralists. Thorn bushes are utilised for cattle proof fencing and kraals.

Given the importance of trees and shrubs, a method of monitoring and mapping woody vegetation over large tracts of rangeland would provide a useful tool for range management and general land-use planning in developing countries. It would also provide a possible means of monitoring changes in fuel wood resources, which form an important energy source for many countries, including Botswana.

5.3 Mapping woody vegetation using Landsat MSS data.

Standard aerial photography has been used to study bush encroachment (Williamson and Keech, 1983), this involved counting individual trees in a number of sample plots. Mapping woody vegetation in this manner is both time consuming and labourious. The use of a digital, remotely sensed data source would provide the means of speeding up the operation by using computer analysis. It would also eliminate errors associated with the traditional use of aerial photograph mosaics (see section 4.1). The Landsat MSS system would provide the coverage needed over large areas of extensive rangeland. It also has a number of advantages associated with digital, multispectral data sets.The following discussion evaluates the use of the MSS data for the measurement and mapping of woody vegetation.

The choice of 'measurement' used to assess the abundance of woody vegetation will depend on the scale at which the data was collected. If ground survey or large scale aerial photographs are used it is possible to measure the 'density' of woody plants, the number of plants per unit area. This method was used in range surveys carried out at Tsetseku ranch (APRU, 1979), based on ground observations for nine quadrats (20m x 20m). However, the resolution of Landsat pixels is too coarse to allow identification of individual plants, a single pixel area may contain several hundred trees and shrubs in the case of sandveld vegetation. As well as Landsat data, 1:50 000 aerial photography was available for the study area, in this case, only widely spaced trees and shrubs with large canopies were visible as individuals. It is only on 1:10 000 photography (of limited area, including Tsetseku ranch) that small shrubs, of less than one metre in diameter,were visible. Measurement of ´cover´, the proportion of the ground occupied by perpendicular projection on to it of the aerial parts of the vegetation (Greig-Smith, 1957), provides a more useful measure given the form of Landsat data.

In terms of range management, the measurement of cover has an advantage over density, by providing an estimate of land made unavailable for grazing by the presence of woody vegetation. However, cover cannot provide an exact measurement of unavailable land, as the structure of the woody vegetation must be taken into account. Grass may be available beneath a mature tree cover, but not beneath shrub cover.

The amount of woody cover cannot be measured directly from Landsat data, but a relationship between the amount of cover and some measure of reflectance is required to provide a means of estimating this. Investigations into a wide range of relationships between vegetation parameters and reflectance characteristics have been made (Jensen, 1983). Research has generally concentrated on the relationship between healthy green vegetation and the visible red and the near infrared wavelenghts. Lane (1982) tested individual Landsat bands and band ratios against vegetation cover (woody and herbaceous), for semi-arid rangeland in Tanzania. He ranked the usefulness of the relationships; he considered the four best relationships to be; MSS band 7/5 ratio, (7-5)/(7+5) index, MSS band 5, and MSS band 7, in descending order of usefulness. However, the best relationships, those between 7/5 ratio and the cover parameters, were poor ($r = < 0.22$ for both woody and herbaceous cover). Lane's results may have been affected by the wide variation in environmental conditions in the twenty transects surveyed. These varied from areas of brown well-drained loam soils to areas of black clays and grey sandy clays, all with distinctive vegetation types. When he tested these soil/vegetation associations individually, the results displayed even less correlation. Griffiths and Collins (1983), working in northern Kenya, found a negative correlation between non-green canopy cover and reflectance in Landsat MSS band 5 ($r = -0.6$), they suggested this was the result of the woody vegetation masking high soil reflectances.

In the present study, the target area was specifically selected to minimise the affects of wide variations in environmental conditions. One of the terrain types identified during the provisional terrain analysis of the main study area, was selected. This restricted initial sampling and analysis to an area displaying an internally consistent suite of spectral response characteristics, which are associated with particular soil, vegetation and other landscape features (section 4.1).

The provisional terrain type 'class 6' (the 'Kalahari Sandveld' terrain type of the final terrain analysis classification) was chosen. This terrain type covered a large part of the main study area, and encompassed areas traditionally associated with cattle rearing (the Boteti and Nghabe River zones), and the Haina Veld, an area of proposed expansion of controlled ranching (UNDP/FAO, 1977).

Detailed ground data was collected at Tsetseku ranch, to provide information on vegetation composition and structure, soil, and topography. An understanding of these factors, in terms of their effect on the spectral responses recorded by the Landsat system, was important. It was essential to eliminate any factors which may have affected an otherwise useful relationship between woody cover and a reflectance variable, for example 'shadow effects' caused by changes in topography. Changes in the composition of tree and shrub species might also result in significant changes in response values. The vegetation data would also provide information on such matters as the browse value of the sandveld vegetation and whether this varied in space. This type of information could be used to make more detailed assessments of the use of the Landsat data for range evaluation. Because of problems of accessibility, the ground survey was not used to sample woody cover values. The 1:50 000 aerial photography of the study area was used to obtain estimates of woody cover values. These values were used as the main test of the relationship between tree and shrub cover and Landsat MSS data values. The ground data, together with analysis of 1:10 000 aerial photography of Tsetseku ranch, were used to check the cover data obtained from the 1;50 000 aerial photography.

It should be noted that the green leaves of both woody vegetation and herbaceous layer vegetation are likely to produce very similar spectral response curves. This will affect any measurement of woody cover based on reflectance data. This problem was overcome in the present study by selective timing of data collection at all levels. The Landsat, aerial photographic and ground data used in the study were all collected during the period of the year in which grass cover was declining to its lowest level, in July (APRU, 1975), while the deeper rooting woody vegetation still had a canopy of green leaves. The drought conditions affecting southern Africa during the early 1980's added to the effect, with increased demand by cattle for the remaining grass cover. By the time of ground data collection (April - June), the only healthy, green grass cover remaining, was that protected beneath dense shrub cover. Any reflectance from grass cover beneath woody vegetation, if it was able to penetrate the canopy, would effectively be contributing to the response of the woody cover.

5.4 Tsetseku Ranch ground investigation site.

5.4.1 Introduction.

Tsetseku ranch is located approximately thirty kilometres south-west of Maun and ten kilometres off the main Maun-Toteng road at Gwexwa. It lies at an altitude of 930m above sea level. The ranch is run by the Animal Production Research Unit (APRU) Ministry of Agriculture (Botswana). The ranch is situated on the boundary of two of the terrain types identified during the terrain analysis, the Kalahari Sandveld and the Riverine Zone. The majority of the ranch area is sandveld, with riverine fringe woodland and molapo grassland elements occurring only along the north-west boundary fence (fig. 5.1).

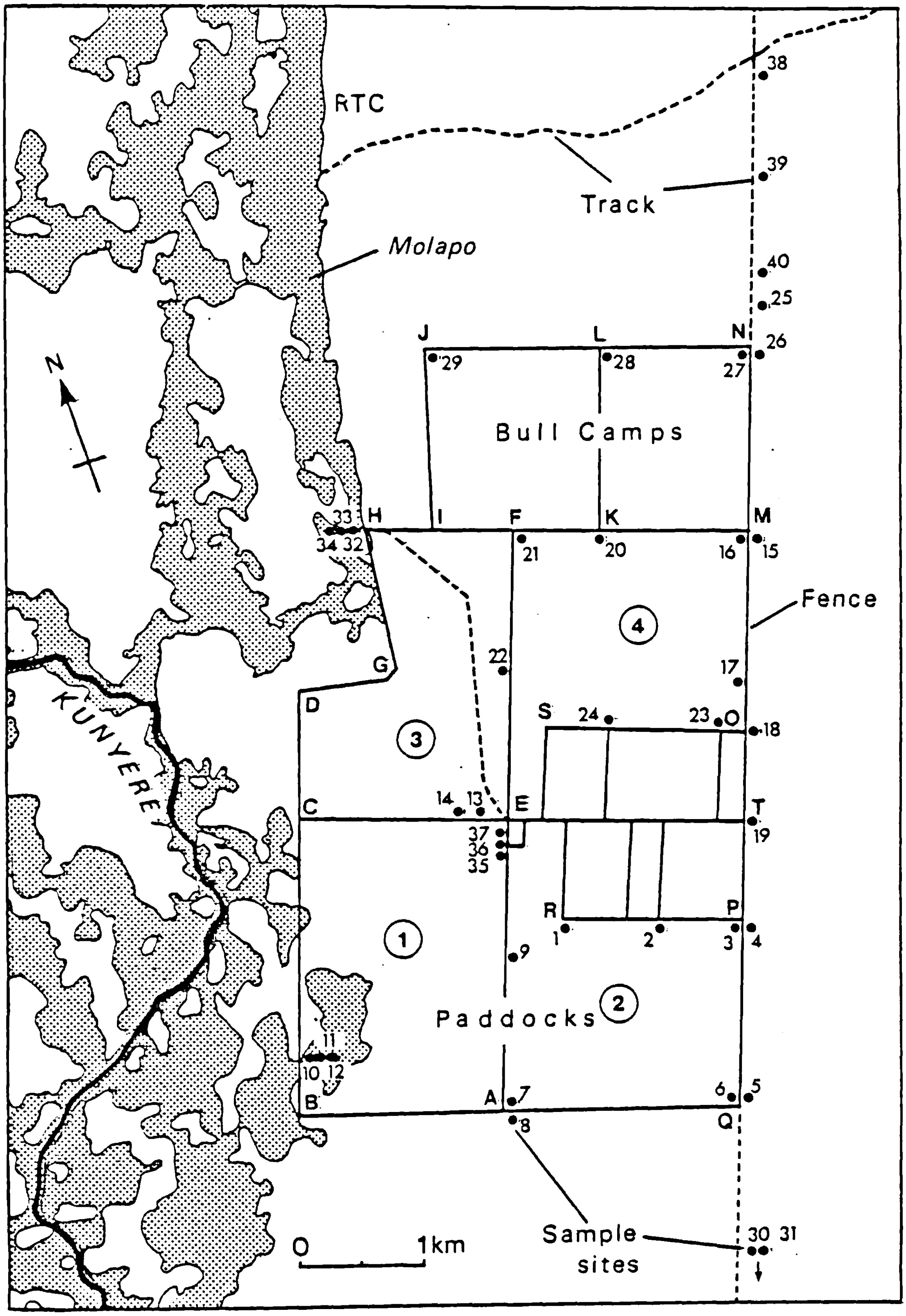


Fig. 5.1 Tsetseku Ranch ground survey site.

Tsetseku ranch and the surrounding common rangeland was chosen as the site for detailed ground data collection for a number of reasons:

a) It provided a representative site within the terrain type chosen for analysis, the Kalahari Sandveld type (provisional class 7).

b) The landuse of the ranch and it´s surroundings was rangeland for cattle production.

c) Data from range monitoring surveys at the ranch was available for the period of the 1970´s (APRU, 1975, 1978, 1979, pers. comm.).

d) Fence and cutlines associated with the ranch and surrounding communal land provided a framework for ground data sampling and for subsequent relocation of sites on the aerial photography.

e) Colour aerial photography at 1:10 000 (limited to the Tsetseku area) and 1:50 000 black and white aerial photography, were acquired for the ground data collection period.

f) An aerial photographic survey (colour) of Tsetseku ranch (and including part of the surrounding communal area) was flown during the period of the ground survey. This provided two scales of aerial photographic cover over the site (the other at 1:50 000).

The ranch lies at the eastern side of the Kunyere fault line, where the Xaudum channel flowing from the north meets the fault and becomes known as the Kunyere. This seasonal water course is not a water source for the ranch, although it is important for nearby cattle posts. All the ranch's water is supplied from a single bore hole.

Tsetseku ranch consists of a total area of 1902 hectares, which is divided into four main paddocks around a central kraal and two smaller paddocks which are maintained as 'bull camps' (see table 5.1). Within paddocks 2 and 4, areas of 17, 34 and 51 hectares have been set aside for stocking trials, with stocking rates of 4, 8 and 12 hectares per LSU respectively.

Table 5.1 Paddock areas, Tsetseku Ranch (APRU).

Paddock	Area (ha)
1	391
2	437 *
3	312
4	437 *
5	169
6	156

(* stocking trials included).

Stocking rates at Tsetseku have been maintained at between 9 and 16 ha/LSU (APRU, 1979)(see table 5.2), compared with rates of about 1 ha/LSU in the surrounding communal land (UNDP/FAO, 1977).

Table 5.2 Stocking Rates 1974 - 1979 (APRU 1979).

Year	Area grazed (ha)	Stocking rate (ha/LSU)
1974	1902	16.5
1975	1902	14.5
1976	1902	12.4
1977	1902	12.4
1978	1902	10.1
1979	1902	8.8

5.4.2 Geomorphology and soils.

Tsetseku lies on a substrate of unconsolidated Kalahari sands. The soils have developed from the Kalahari deposits and tend to be fine grained, very freely draining and non-calcareous. Structure is poorly developed and horizonation is ill defined. Starring (1979) classifies the soils of the area as Dystic and Eutric Regosols (FAO Classification). They are generally very pale in colour, pale greys to brownish greys.

Sand ridges, alternating with depressions, are found throughout the ranch and surrounding sandveld. These are probably the remains of old dune features, which have been eroded or stabilised by vegetation, resulting in a disrupted east-west linear pattern. This pattern is clearly visible on the 1:10 000 colour aerial photography when viewed under a stereoscope.

5.4.3 Vegetation and wildlife.

The predominant vegetation type at Tsetseku is low tree and shrub savanna, which is characteristic of the Kalahari Sandveld. Some dense riverine woodland and molapo (floodplain) grassland occurs within paddocks 1 and 3.

A mixture of Acacia and Grewia species generally occupy the tops of the ridges and level areas within the sandveld terrain. The tree, Terminalia sericea, is locally dominant, mainly on the upper slopes of the ridges, especially where the soils are loose, unconsolidated sand. Depressions between the ridges are dominated by Acacia trees and shrubs. Tall, mature Acacias are often found on the periphery of rain pans. Grewia species also form an important part of this vegetation type.

The shrub, Dichrostachys cineria, is found throughout the ranch and surrounding sandveld, and is regarded as symptomatic of bush encroachment. It sometimes forms localised patches of extremely dense shrub, to the exclusion of other species, on the sites of abandoned kraals.

The riverine fringe woodland forms areas of very dense vegetation at the edge the ranch. The canopy layer is generally between 10 and 12 metres high, with some lower layer vegetation and epiphytic creepers. The dominant trees species at Tsetseku were, Croton megalobotrys, Combretum sp., Lonchocarpus nelsii and various Acacia species. Members of the genera Grewia and Rhus, together with Ximenia americana, are found as shrubs in the understorey.

A few large wild animals are found on the ranch and surrounding area. The Greater Kudu (Tragelaphus strepsiceros), an antelope, is commonly found, it is essentially a browsing animal and is not in direct competition with cattle. The Grey Duiker (Sylvicapra grimmia), a small antelope, is commonly seen. The duiker is a grazer and browser. A large rodent, the Spring Hare (Pedetes capensis) and Ostrich (Struthio camelus) are also frequently seen.

5.5 Design of ground sampling procedures for use with satellite data.

Decisions regarding sampling procedures and the location of ground sampling sites are of great importance. This is especially significant if the data is to be used to derive a classification which will be extrapolated over a large area. Limits to classification should take into account the representativeness of the ground data for the whole area to be classified.

A decision must be made on the most appropriate or applicable type of sampling for a given target area. Selection of a sampling design may have to take into account factors beyond the control of the study, for example accessibility, if any meaningful results are to be gained.

The choice of sampling procedure is generally between the use of 'probability sampling' and 'purposive sampling'. The former has the advantage that it is not based on a subjective selection of sites and that it is possible to obtain a 'formal statement of the representativeness of the sample' (Justice and Townshend, 1981a). Purposive sampling does involve subjectively choosing sites which are considered 'typical' of some aspect of the landscape. Purposive sampling procedures do have a number of practical advantages over probability sampling, these are discussed below.

Probability sampling sites may either be randomly or systematically selected. A random selection can be obtained by placing a grid over a map or image of the target area and locating sites using pairs of random numbers as coordinates. A systematic selection can be obtained using a grid to regularly position sites over the target area.

However, both of these methods of site selection may be difficult to implement in certain conditions. Accurate location of sites in the Kalahari Sandveld, away from major features such as roads and rivers is difficult, the terrain consisting of relatively featureless depressions, gently sloping ridges and level plains. As well as problems of location, access to sites which are distant from a track or road is difficult in this terrain.

It is possible to use a modified type of systematic selection of sites based on the networks of cutlines and fencelines that exist within the area. These are often visible on aerial photographs and marked on maps (although cutlines often become overgrown between the date of mapping and the field survey).

The use of any grid for systematic sample selection, risks alignment of the sites coinciding with that of natural recurring features such as dunes, leading to the possibility of over or under sampling certain elements of the terrain.

Purposive sampling has the disadvantage of being subjective, but has practical advantages over other methods in areas of difficult terrain. Purposive sampling is effective in reducing the time spent gathering field data, which is important where field work may be of restricted duration or where there may be a shortage of trained field staff. The procedure also has the advantage of allowing sites to be chosen which are accessible, although the 'representativeness' of such sites might be called into question. The effectiveness of such sampling is dependent on local knowledge of the field workers or on assistance from local sources. In the case of the Okavango region a number of individuals associated with various government departments were able to supply detailed information concerning the area. This information greatly assisted the selection of sites where purposive sampling was used.

Sampling 'units' are usually in the form of 'areas', rather than 'points' when used in remote sensing studies, this is especially true for relatively low resolution imagery, such as that from the Landsat system. Point samples are sometimes used with high resolution aerial photographs, but in general this is not appropriate because of the nature of the characteristics to be measured (Justice and Townshend, 1981a). The size and shape of the sample areas is determined by the type of imagery used and the particular environment under investigation.

The choice of sample unit dimensions is governed by the two factors mentioned above. The effect of imagery type upon sample plot size is linked to it's resolution, while the environment in which the data is being collected may impose both theoretical and practical constraints.

The resolution of the imagery, whether photographic or linescan data, is important for the following reason; if sample units are used which are smaller in area than the basic unit of image resolution, for example a Landsat pixel, data may be collected which is unrepresentative of the scale of information contained in the imagery. Material of a given resolution restricts the information available to within certain practical limits. For line scan data, with specific dimensions for each 'pixel', it will be easier to define a sample unit's size based on resolution than is the case for photographic imagery.

Justice and Townshend (1981a) argue against the use of ground sampling areas of size equal to, as well as less than, a pixel. This is on the grounds that 'problems of accurate ground location in terms of an external coordinate reference system' would be very difficult. If ground location is determined to within plus or minus half a pixel, this means that no single pixel-size area on the ground can definitely be associated with one specific pixel. They describe an equation by which an appropriate area for a sample, based simply on the resolution of the imagery used, can be calculated;

$$A = P(1+2L)$$

Where A = Sample area

P = Pixel dimensions

L = Accuracy of location in terms of number of pixels.

The equation gives a sample unit size of 158m x 158m for a Landsat MSS pixel to plus or minus half a pixel, or 237m x 237m to plus or minus one pixel. If good topographical maps are not available they suggest increasing the dimensions further.

In the case of aerial photographs the choice of sample unit size is less easy to define, but must reflect the practical limitations of the type and scale of the product used, which is dependent on the resolution of the original negatives.

The above method of determining sample dimensions represents an ideal situation where the resolution of a single type of imagery is the only constraint on the matter. However, environmental and logistical problems may prevent the use of sample units arrived at purely on the basis of image characteristics. In the Okavango area the nature of the terrain and the difficulty of preparing large sample areas or ´quadrats´ requires the use of a stepped method of sampling using aerial photographs as an intermediate level of data.

The availability 1:40 000 scale aerial photography prior to the field survey and of 1:10 000 and 1:50 000 scale photography subsequently, provided an appropriate level of data between the Landsat imagery and the ground data. Actual ground features were discernable on the photographs, such as trees, shrubs, fences and roads, thereby increasing the accuracy with which ground sampling sites were located. The photography provided a useful source of data for analysis of the Landsat imagery (see section 5.8).

Another factor which has an effect on the size of sample units is concerned with the internal homogeneity of samples. If samples are to be used as training sets for classification procedures, the degree to which the sample can be said to represent a single terrain type or vegetation community will be critical to the success of the operation. Decisions on the degree of variance acceptable and a definition of a homogenous unit must be made and this will influence the size of sample units. Where vegetation patterns are complex and where variations in ground cover occur gradually rather than being delimited by sharp boundaries, locating sample sites and deciding on the correct size for these is very difficult, these problems are often compounded by variability of soils and of relief.

It is conventional to use a square sample area or quadrat for vegetation analysis, but a number of other shapes have been used. One problem which may be minimised by use of a circular quadrat is that of 'edge effect', the problem of inclusion or exclusion of individuals at the edge of the sample. To minimise this effect, the sample area must have a low perimeter to area ratio, this is provided by a circle. A circular quadrat is often impractical in certain circumstances especially at large scales. Rectangular quadrats are more easily marked out if a large quadrat is required, and if very long, thin rectangles are avoided, the edge effect will not be too great (Kershaw, 1973; Kellman 1975). Rectangular plots are thought to have an advantage over the standard square in eliminating variance between plots. Kershaw (1973) presumes this is a result of 'a rectangle crossing a high density patch and an adjacent low density patch simultaneously and thus leveling out the variance over the whole area', which is less likely to occur within a square quadrat.

5.6 Sampling scheme and data collection (Tsetseku Ranch).

5.6.1 Sampling scheme.

The nature of the terrain in which Tsetseku ranch is situated, made it difficult to successfully use a random or simple systematic scheme of sampling. The location of sites generated by either method would have been extremely difficult. The ranch is, however, divided into a number of paddocks by a network of fences and tracks, which provided a network of intersecting, straight lines which could be detected on aerial photographs. These photographs together with plans provided by APRU, were used to plot the lay-out of the ranch onto the 1:50 000 scale topographic map of the area. The network was then used as the basis for establishing the position of sites. A form of systematic sampling was used, sites were located at fence intersections or mid-points along fencelines (see fig. 5.1). However, it was evident that given the time and resources available for ground survey, a certain number of sites would have to be subjectively chosen so as to include data on specific elements of the vegetation. This was the case with the molapo grassland (sites,10,11,12,32,33, and 34), and an area of experimental bush clearance (sites,35,36, and 37). Information concerning vegetation associations at Tsetseku was available from APRU (pers. comm. and unpublished material), this provided a useful basis for selection of these latter sites.

As a number of levels of (temporally contiguous) data were to be available for analysis subsequent to the field survey, it was decided that a stepped method of sampling should be used. This meant that a smaller plot size could be used than if the ground data was to be directly compared with the Landsat data. Instead, the 1:10 000 and 1:50 000 scale aerial photography was to be the main source of data used to analyse the Landsat imagery, with the ground data providing additional information on aspects of the landscape which could not be identified from the photography. The ground data survey was also designed to provide some comparisons with range survey data collected by APRU, in the period prior to the present study. Smaller plot sizes provided a number of important practical advantages in terms of positioning and marking out the plots, and of accurately recording data.

A rectangular quadrat of 250 square metres (10 m x 25 m), was chosen on the basis of practical considerations in the field, and location of sites on the aerial photographs. Two quadrats were marked out at each site, one with its long axis perpendicular to the nearby track or fence, and the other parallel. The quadrats were positioned at least 10 metres away from the track or fence, to allow for any influence of these features on local vegetation growth. Vegetation often appeared to be taller at the edge of tracks, possibly the result of increased run-off from the bare-ground of the track, or the lack of competition from vegetation in the bare area.

5.6.2 Data collection.

A general description of each site was recorded (see appendix A), providing details of the local topography and evidence of erosion. The landuse, either ´managed ranching´ or ´uncontrolled common grazing´ was recorded. Within each of the quadrats, a number of specific soil and vegetation characteristics were recorded.

Soil surface characteristics recorded include; colour (Munsell classification), texture, structure and moisture status (see section 4.7.4). Estimates of the area of bare ground and of surface litter were made for each quadrat (<10% = very low, 10-20% = low, 20-40% = medium, 40-60% = high, >60% = very high). No outcrops of solid geology or of concretionary deposites, such as calcrete, were recorded at Tsetseku.

Vegetation characteristics include a general description of the site; recording vegetation structure and an estimate of cover (<10% = scattered, 10-20% = sparse, 20-40% = medium, 40-60% = dense, >60% = very dense), height of the tree and shrub layers, and the condition of any grass cover. Specific vegetation parameters were recorded inside each quadrat. A measurement of the basal cover of grasses was made (this is regarded as a more appropriate measure than the above ground canopy cover, which varies markedly with variations in season and management practice (APRU, 1975)). A 25 metre tape was stretched between two marker posts and a 0.5 centimetre rod was lowered at 5 centimetre intervals. The presence or absence of the basal part of individual grass plants was thus recorded for 500 points per quadrat. The results were expressed as percentage basal cover. The total number of trees and shrubs per quadrat were recorded, together with sub-totals for individual species. Only trees or shrubs rooted within the quadrat were recorded. Trees were defined as being a woody plant over 3 m in height and with a distinct trunk(s) (multiple stemmed individuals were common in the study area). Shrub layer plants were defined as between 0.5 and 3 m.

Data was recorded at a total of 40 sites (80 quadrats) throughout the ranch and surrounding common rangeland. In addition to the 40 main sites, eleven, 10 m x 30 m quadrats were later established to provide cover and profile diagrams of 'typical' sites within the main vegetation types (Terminalia sericea dominated slopes, Acacia dominated depressions, and areas of mixed tree and shrub savanna). Cover diagrams were drawn by measuring individual crown diameters and projecting these onto the 'ground area' of the quadrat. This was done for all the aerial parts of trees and shrubs which were perpendicular to the quadrat area, whether 'rooted' or not. Profile diagrams were drawn with the aid of tape measures and graduated ranging poles. The profiles provide an illustration of the stratification of the woody vegetation, and the position of species within this.

As well as the detailed recording of vegetation at specific sites, changes in vegetation were recorded along paced transects based on the fencelines at Tsetseku (between points: A/E, A/Q, E/C, E/F, E/H, E/T, F/M, I/J, M/N, M/O, Q/T). A single transect between point E and F (see fig. 5.2) was levelled to provide a cross section of the ridge and depression topography and to study the relationship of the vegetation types to topography. Because of the difficult nature of the terrain, it was not possible to level a section perpendicularly to the east-west trend of the ridges, the transect E/F was offset at about 35 degrees to the optimum line.

5.7 Results of ground data collection, Tsetseku Ranch (1983).

5.7.1 General.

No information was available concerning topography for the Tsetseku area prior to the 1983 field survey. The transect, levelled between points E and F inside the ranch, gives an indication of the general topography (fig. 5.2). Slope angles were calculated for 30 metre sections of the transect and corrected to take into account the orientation of the section away from the optimum line, perpendicular to the trend of the linear ridges. The steepest slope angle did not exceed two degrees over the whole section. The majority of the slope sections (along the 2.3 kilometre transect) were less than one degree. The maximum height difference between the centre of a depression and the apex of a ridge was approximately 3 metres, over a horizontal distance of 145 metres. These low slope angles, together with high sun angles at time of Landsat data collection over Botswana, means that 'topographic effects' which may reduce image clarity (Justice and Townshend, 1981b) are not a problem. All of the sample sites were on level ground. Within the sample quadrats there was no evidence of small scale morphological features, such as rills. The ground surface was essentially smooth and flat, some small hummocks were found, usually associated with collection of wind blown sand around an object, such as a tussock of grass. There was little evidence of surface erosion, except for the effects of trampling and some movement of sand particles by wind action.

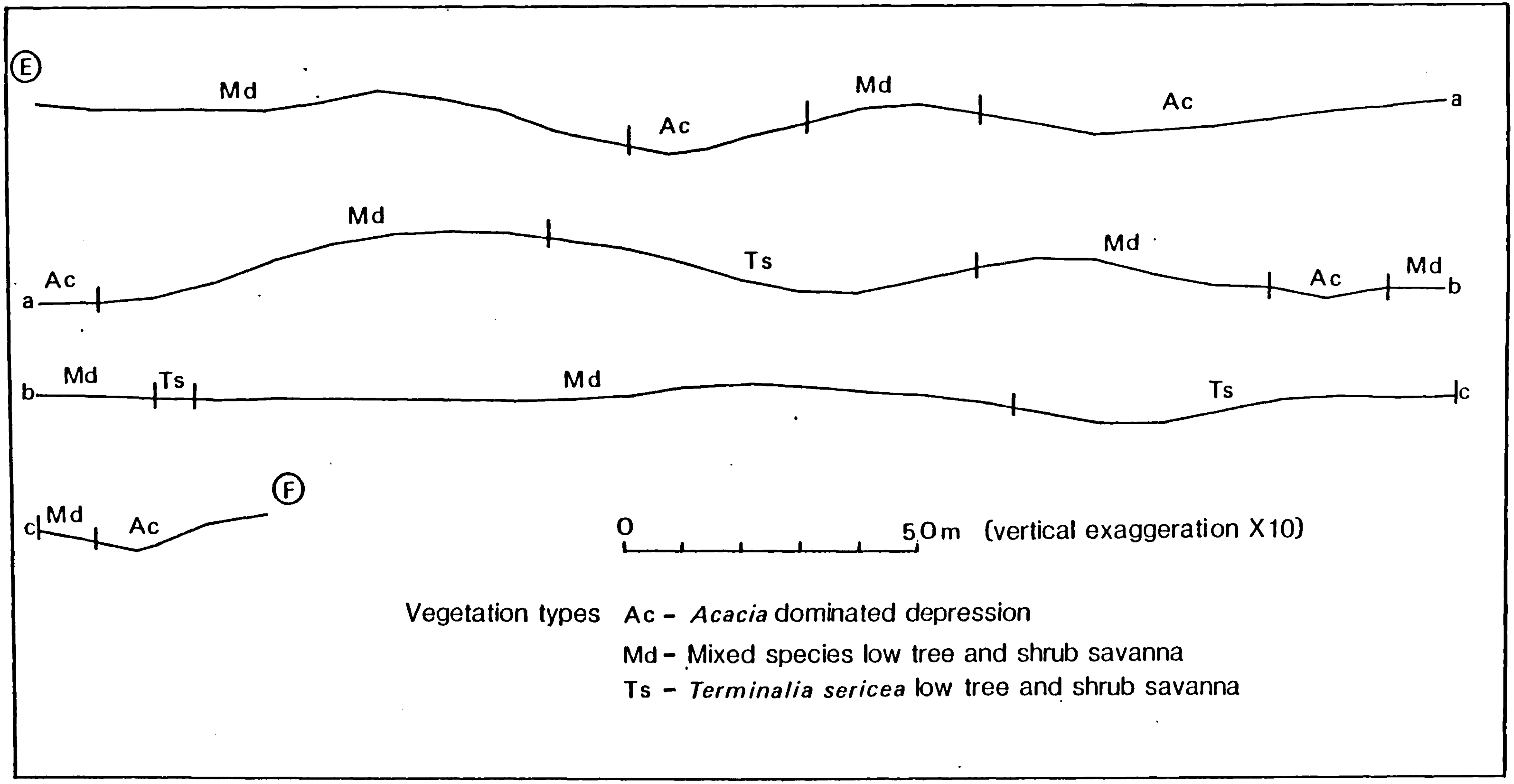


Fig. 5.2 Transect E-F, Tsetseku Ranch.

5.7.2 Soils.

The majority of the sample sites had 'light grey' (surface) soil colour (10YR 7/1 to 10YR 7/2, accounting for 23 (70%) of all the sandveld sites). Surface colour variation in terms of Munsell 'value' and 'chroma' levels was limited, ranging from 'white' 10YR 8/1 (2 sites) to 'light brownish grey' 10YR 6/2 and 2.5Y 6/2 (4 sites). These colour values are consistent with the observations made throughout the Kalahari Sandveld terrain type. The soils of the molapo grassland at Tsetseku (Riverine Zone) were generally darker, 'very dark grey' (10YR 3/1) to 'dark grey' (10YR 4/1), with localised patches of 'light grey' (10YR 6/1) where deeper soil had been exposed.

Surface soil texture was sandy within all the sandveld sites. Only where a rain pan occurred was there any accumulation of finer material (clay) at the surface in the sandveld. Small pans were found along the linear depressions throughout the ranch (see fig.5.3). The molapo soils were also sandy within the ranch area. The soil at all sites was structureless. The surface material was usually loose or formed a thin (0.5 - 1.0 cm), brittle crust (the 'armouring' effect of rain splash).

Surface litter cover at the sandveld sites was generally low (10-20%) to medium (20-40%) (58% and 22% of the quadrats respectively). Litter was mainly in the form of dry leaves from trees and shrubs. Correspondingly, the area of bare soil within the quadrats was generally medium (20-40%) to high

(40-60%) (45% and 37% of the quadrats). The molapo soils were usually higher in surface litter, including fine material which tended to become mixed with the soil, adding to its darker colour. Identifiable litter was almost entirely dead grass material. Exposed soil surface was usually low.

The quadrat data suggests that the soil surface conditions within the sandveld area were relatively uniform. This is probably true for the majority of the Kalahari Sandveld terrain type within the study area. Areas of exposed soil would present a highly reflective surface in all four wave-bands recorded by the Landsat MSS system. The effect of light coloured surface material would be enhanced by low organic matter and good internal drainage of the sandy soils, providing very dry surface conditions.

5.7.3 Vegetation.

The main vegetation types, identified during the terrain analysis (section 4.8.2(f)) within the Kalahari Sandveld, were represented within the sample sites at Tsetseku. These were mapped for the ranch area using 1:10 000 and 1:50 000 aerial photographs, and transect (ground) data (fig. 5.3). The types represent variations in structure and species composition within the general physiognomic vegetation type, 'low tree and shrub savanna'. These vegetation types appear to be related to changes in topography, they are; Acacia dominated depressions and minor plains between linear ridge features, mixed species (mainly dominated by the genera Grewia and Acacia) on the ridge tops and slopes, and Terminalia sericea

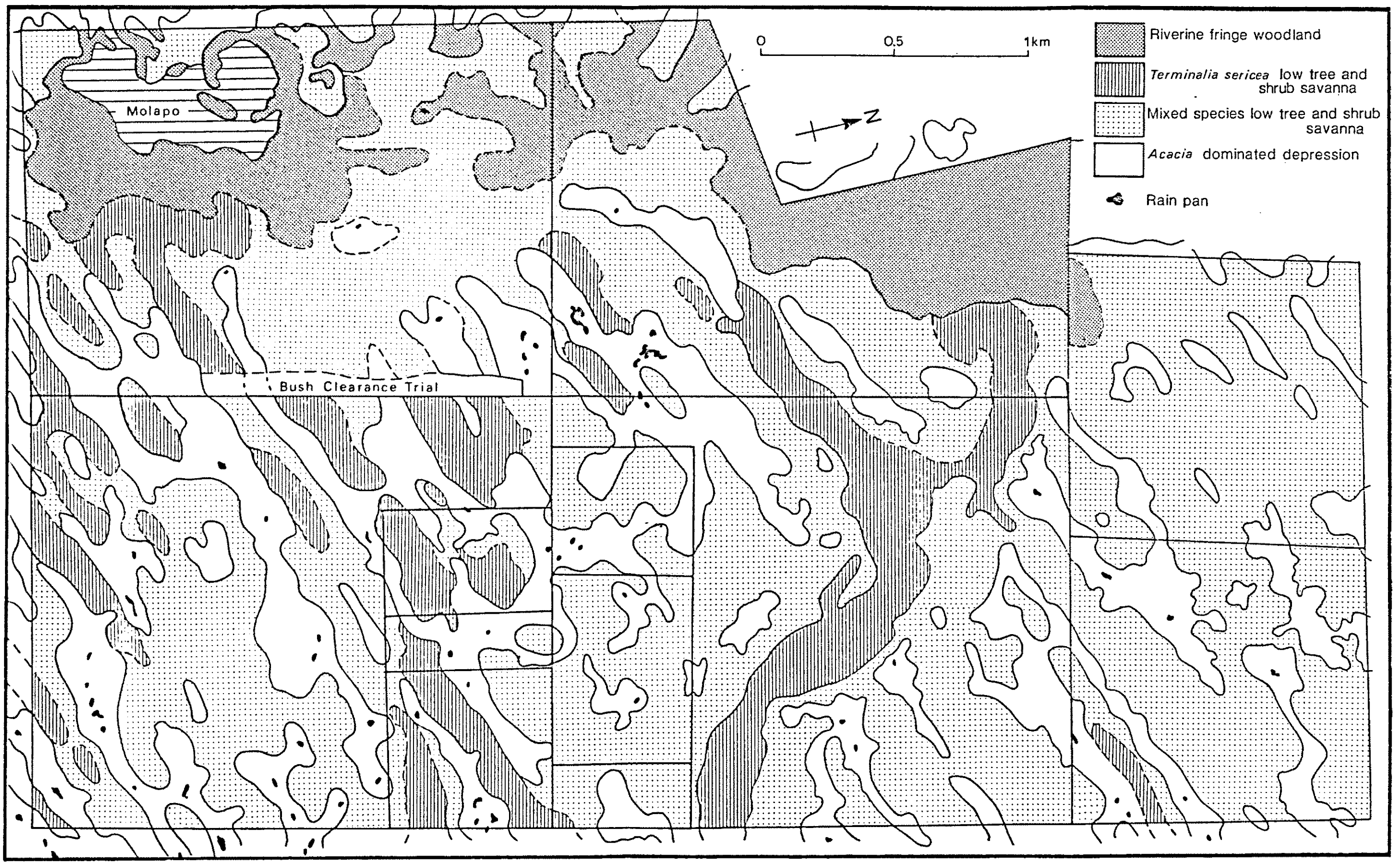


Fig. 5.3 Vegetation map of Tsetseku Ranch.

dominated vegetation on the ridge slopes (see figs. 5.2 and 5.4). Boundaries between types were not always clear on the aerial photographs. Transition zones between vegetation types were found, especially between the mixed species and T. sericea low tree and shrub savanna types. An estimate of the areas occupied by each vegetation type at Tsetseku was made from the map (table 5.3).

The figures in table 5.3 give an indication of the relative importance in terms of areal coverage, of the vegetation types within the sandveld. The larger part is occupied by the mixed species low tree and shrub (58%), the Acacia dominated depressions and the T.sericea low tree and shrub accounting for the remaining 42% (27% and 15% respectively).

60 of the 80 quadrats sampled during the survey, fell within the sandveld area. Systematic selection of sample sites led to the mixed species savanna being most frequently sampled (52% of all sandveld quadrats). The remaining quadrats are divided between; Acacia dominated depressions (23%), T.sericea savanna (5%), transition zone vegetation between T.sericea and mixed species savanna (17%), and a site dominated by the shrub D. cinerea (3%). Given the areal estimates for each vegetation type, these figures appear to be representative. The transitional vegetation type accounts for the slightly lower than expected figures for the mixed species and T. sericea savanna types.

Fig. 5.4a Acacia dominated depression.

Fig. 5.4b Mixed species low tree and shrub savanna.

Fig. 5.4c Terminalia sericea low tree and shrub savanna.

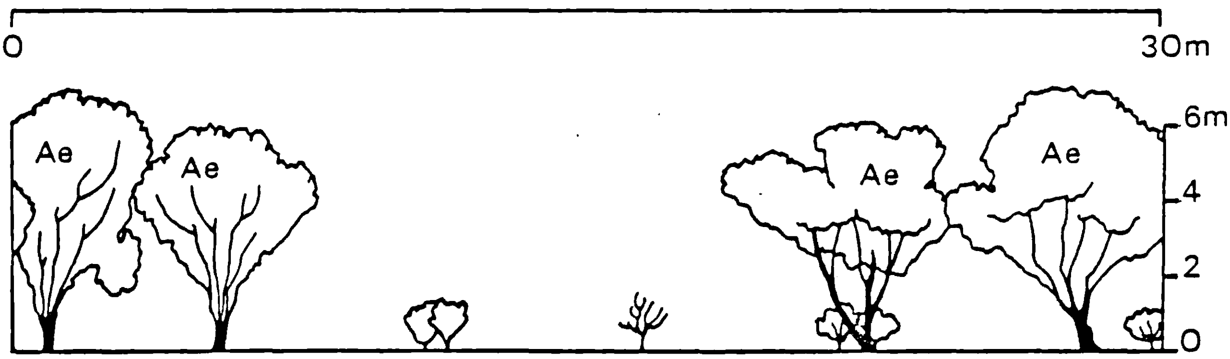
Table 5.3 Area of the Main Vegetation Types at Tsetseku Ranch (1983).

		Percentage (%)	Hectares
Kalahari Sandveld	- *Acacia* dominated depressions.	24	451
	- Mixed species savanna.	50	957
	- *T. sericea* savanna.	13	247
Riverine Zone	- Fringe woodland.	11	218
	- Molapo grassland.	2	29
	TOTAL.	100	1902

The general descriptions of the vegetation at each site are given in appendix A. Grass cover was very low throughout the sandveld during the survey period. Healthy, green grass was found only beneath dense, protective bush cover, where protected from grazing animals. The height of the shrub layer usually varied between 0.5 and 2.5 m. The tree cover rarely exceeded 4 to 5 m, except in the depressions where individual Acacia trees reach 6 to 7 m in height (usually at the edge of rain pans). Profile diagrams (fig. 5.5) of the main vegetation types indicate the relationship between the tree and shrub layers.

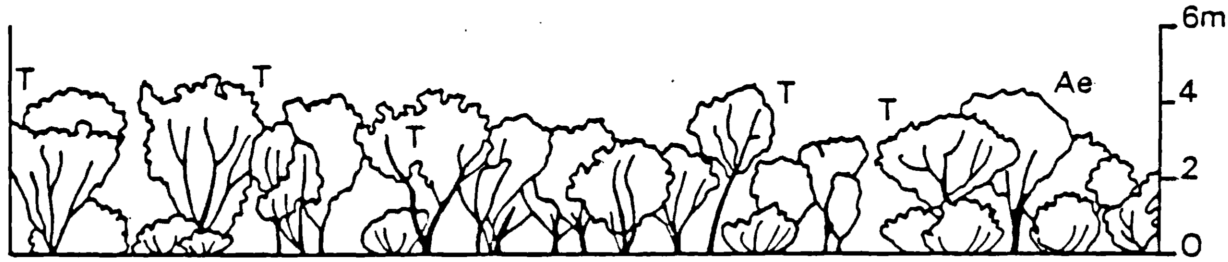
The recorded basal cover of the grasses within the ranch at Tsetseku was 2.9% for the sandveld quadrats. Range surveys by APRU (1979, 1980) at Tsetseku for the years 1974 and 1977-80, gave a mean basal cover value of 3.0%, fluctuating between 1.5% and 6.0%. The values recorded for the individual vegetation types during the 1983 survey are given in table 5.4.

A difference was noted between basal cover values inside the ranch (2.87%) and those of the communal rangeland (1.34%) for the sandveld vegetation. This was probably due to high, uncontrolled stocking rates in the communal range, leading to over-grazing. This difference was tested for significance, using data from the mixed species quadrats to provide comparable figures. A two-tailed Student t test (with a Bessel Correction for small sample size) was used. The two sets of data were found to be significantly different at the 99.9% level (mean values of 2.95% inside the ranch and 1.96%



a) Acacia dominated depressions.

b) Mixed species low tree and shrub savanna



c) *Terminalia sericea* low tree and shrub savanna.

Ae - *Acacia erubescens*

G - *Grewia* sp.

T - *Terminalia sericea*

(see fig. 5.6 for full species composition).

Fig. 5.5 Profiles of the main vegetation types, Tsetseku Ranch.

Table 5.4 Summary of Vegetation Survey Results - Sandveld (Tsetseku/1983).

	Basal Cover (%)	Trees/ha	Shrubs/ha	Woody spp./ha
Acacia dominated depressions.	1.9	56	557	612
Mixed species savanna.	2.6	59	769	828
T. sericea/mixed species savanna.	1.6	82	680	762
T. sericea savanna.	1.3	171	959	1131

for the communal rangeland).

The number of woody plants per hectare (ha) recorded at Tsetseku by APRU (1979 1980), rose steadily from 560/ha in 1974 to 1060/ha in 1979. This may be interpreted in three ways. Firstly, it represents a recovery in the number of woody plants following the drought period of the 1960's (woody savanna vegetation tends to die back during periods of insufficient residual soil moisture (Walter, 1971)). Secondly, it maybe the result of grazing pressure on the grass layer, leading to a swing in favour of woody vegetation , in terms of competition for moisture, nutrients and space. Thirdly, it may have been the result of a combination of these factors. The results of the 1983 survey show a decline in woody plants to 820/ha for the ranch (800/ha for all the sandveld quadrats). This may be related to declining rainfall during the period of the early 1980's. Some difference in the data may also result from differences in sample size between the two studies (the APRU results were based on only nine (20 m x 20 m) quadrats).

The number of woody species (as well as tree and shrub sub-totals) was lowest in the depressions and highest for the areas dominated by T. sericea. The same ranking was found when estimates where later made of percentage cover within each of the main vegetation types (table 5.5). The estimates of cover were made from aerial photographic data of the Tsetseku area (section 5.8).

Table 5.5 Estimated Percentage Woody Cover - Sandveld Vegetation Types.

(Tsetseku/1983)

	Woody Cover (%)	Number of samples	Standard deviation	mean crown diameter (metres)*
Acacia dominated depressions.	17.6	16	5.5	2.6
Mixed species savanna.	30.3	15	5.6	1.8
T. sericea savanna.	45.0	14	6.7	2.6

(* Crown diameters calculated from measurements taken while plotting cover diagrams. 41 random samples per vegetation type).

The data was tested for significance using a two-tailed Student t test (with Bessel Correction). The percentage cover values between the vegetation types was found to be significantly different at the 99.9% level. The cover (fig. 5.6) and profile diagrams (fig 5.5) give an indication of the relationship between the structure of each vegetation type and cover.

The species composition of each quadrat (with sub-totals for trees and shrubs) was recorded (see appendix A). Table 5.6 shows the percentage occurrance of three of the dominant genera of woody plants within the sandveld vegetation types.

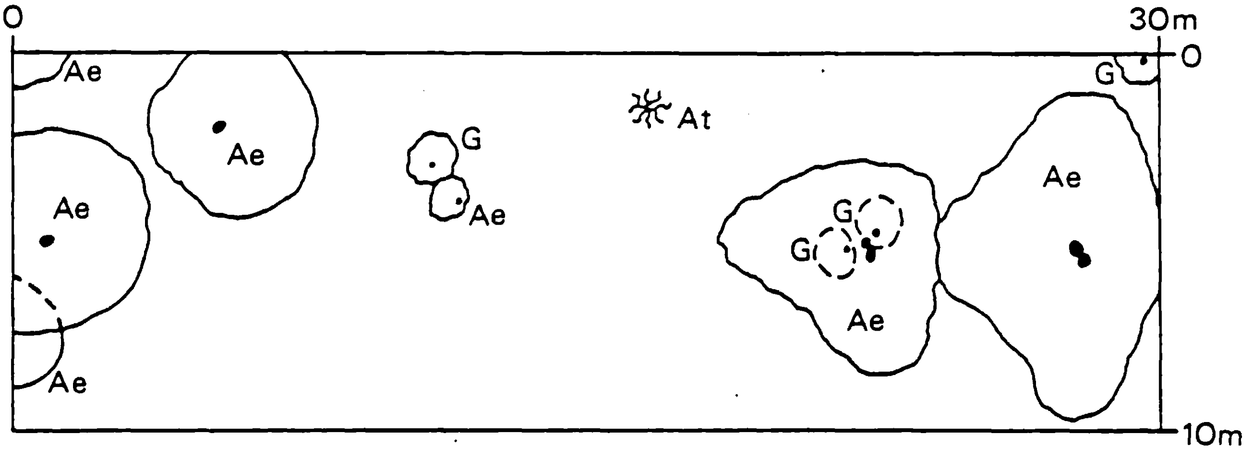
The cover and profile diagrams indicate the relationship of the various species within the vegetation types. For example, T. sericea can be seen to dominate the upper strata of the woody vegetation in figure 5.4c, while Grewia spp., and D. cinerea are occupy the understorey.

5.7.4 Range condition.

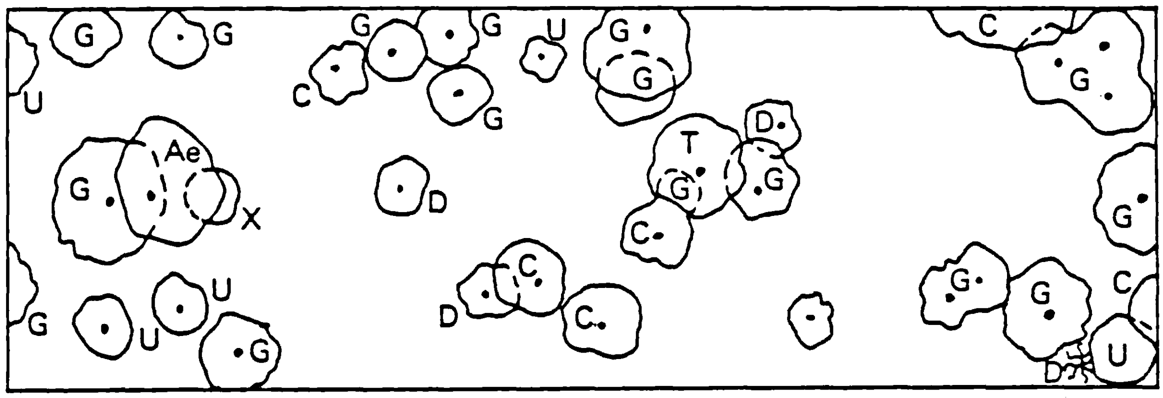
Using the data gathered during the field survey, a number of factors affecting range condition and the possible use of Landsat MSS data for range assessment were analysed.

a) Bush Encroachment.

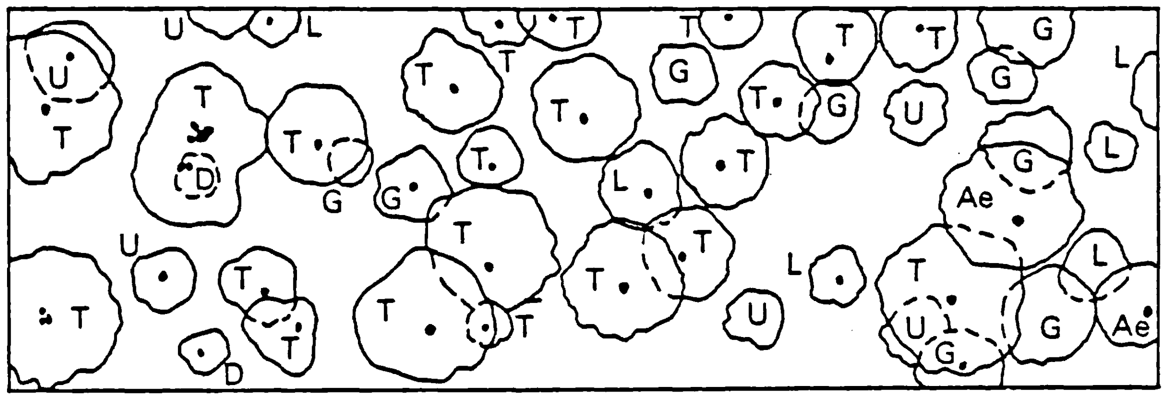
Increase in the numbers of woody plants in rangeland is generally regarded as indicative of range deterioration in Botswana (Field, 1978). It has been suggested that bush encroachment actually leads to a decrease in grass cover (Van Rensburg, 1971b). However, the evidence to date shows only a



a) Acacia dominated depressions.



b) Mixed species low tree and shrub savanna.



c) Terminalia sericea low tree and shrub savanna.

Ae - Acacia erubescens
At - Acacia tortillis
C - Combretum sp.
D - Dichrostachys cinerea
G - Grewia spp.
L - Lonchocarpus nelsii
T - Terminalia sericea
U - Unidentified
X - Ximenia americana

Fig. 5.6 Cover diagrams of the main vegetation types, Tsetseku ranch.

Table 5.6 Composition of Sandveld Vegetation Types by Dominant Genera.

	Acacia spp. (%)	*Grewia* spp. (%)	*T. sericea* (%)	Other (%)	Total
Acacia dominated depressions.	33.1	26.5	0.4	40.1	257
Mixed species savanna.	9.6	37.9	3.0	48.5	689
T. sericea/mixed species savanna.	14.2	35.0	19.5	31.4	226
T. sericea savanna.	4.0	10.1	53.0	32.8	247

weak negative relationship for areas comparable with Northern Botswana (APRU, 1975; Lane, 1981; Griffiths and Collins, 1983). The 1983 Tsetseku field data for all the sandveld sites was used to test for any correlation between percentage basal cover of grass and the number of woody plants per hectare. The Pearson product-moment correlation coefficient (r) was calculated for the bivariate data set, using the Statistical Package for Social Scientists (SPSS and SPSS-X). The data for 62 quadrats was used. The data showed no significant correlation, $r = 0.17$ (see fig. 5.7). The lack of correlation may be related to the decline in rainfall during the early 1980's, by 1982-3 Botswana was considered to be entering a drought period along with the rest of southern Africa. Pressure of grazing during this time may have led to a general loss of grass cover throughout the sandveld terrain. As noted above, only where grass was protected under dense bush cover, was it observed to be healthy and green during the 1983 field survey period. Hence, a tendency for areas with higher bush cover to retain some grass cover may have resulted, while less protected areas will have experienced a decline. If this is true, the ability to map the distribution of woody cover remains important as it could provide a measure of 'available' grazing. Higher amounts of woody cover will restrict the grazing available, whether actively competing with the grass species or not. In practical terms, the effect of bush encroachment on range utilization remains detrimental.

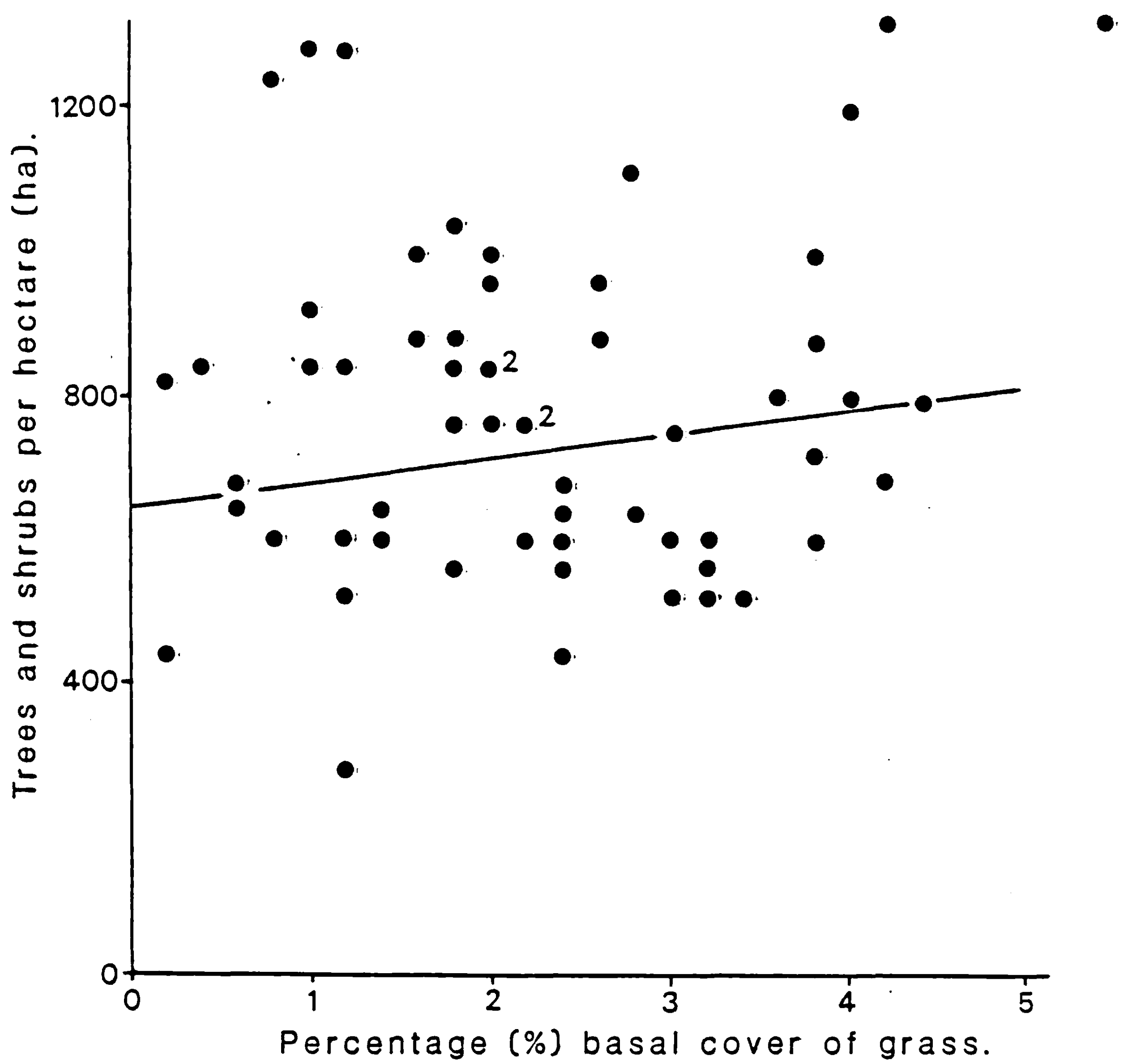


Fig. 5.7 Scatter diagram showing the relationship between trees and shrubs per hectare and percentage basal cover of grass, Tsetseku Ranch (1983).

b) Browse.

Certain species of tree or shrub are beneficial within rangeland in providing browse for domestic stock. Information regarding the composition of the woody component is therefore important in terms of range resource evaluation. A method of classifying and mapping this using satellite data would provide a useful management tool. Desirable browse species often form an important component of rangeland vegetation. In the period 1976-79, the genus Grewia (desirable browse), accounted for approximately half of all the individual woody plants recorded in nine quadrats at Tsetseku (APRU, 1979).

The 1983 field survey included data on the species composition of all trees and shrubs recorded in each of the 25 m x 10 m and 30 m x 10 m quadrats. The identified species were grouped on the basis of their 'browse value'. A list of species and their forage desirability published by the Division of Land Utilization (Botswana Ministry of Agriculture) was used to classify individual species into 'poor', 'intermediate' or 'good' browse (Hendzel, 1981).

The browse value of the trees and shrubs of the sandveld terrain was relatively evenly divided between good browse (45.0%) and poor/intermediate browse (50.7%) within the sample quadrats. A small number of unidentified plants accounted for the remaining 5.3%. The site (39) which was dominated by D. cinerea was not included in the figures, as it represents a localised phenomenon. Dense D. cinerea shrub cover is often found on the site of abandoned kraals. At site 39, 46 (88.5%)

of the 54 recorded trees and shrubs were D. cinerea shrubs (poor browse), the remaining 8 (11.5%) were good browse species. D. cinerea is one of the main indicators of range deterioration associated with bush encroachment in Botswana. It forms an important element of the poor browse component of vegetation throughout the sandveld terrain type (see table 5.7). Other species which dominate the poor browse component include various Acacias and T. sericea. The good browse component is heavily dominated by two species of Grewia (G. bicolor and G. flava), which occur at Tsetseku. Grewia represents about 68% of the desirable plants within the main sandveld vegetation types and about 31% of the total number of woody plants recorded during the survey.

At the level of the individual vegetation types, the mixed species savanna had the highest percentage of good browse plants, while the T. sericea savanna had the lowest value (table 5.7).

The proportion of good or poor/intermediate browse in the various vegetation types is generally determined by the dominant species, not the associated species. The large number of Grewia plants (37.9%) in the mixed savanna type accounts for the high percentage of good browse (53.0%).

The browse aspect of range vegetation must be taken into account in management plans, for example, bush control. Bush control may involve using fire, mechanical (bulldozers, manual clearing), chemical, or biological means (use of certain browsing animals, for example goats, to eat off young shrubs).

Table 5.7 Browse Value of Woody Sandveld Plants, Tsetseku - 1983.

	Acacia depression		Mixed savanna		T.ser/mixed savanna		T.sericea savanna		Sandveld total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Poor/intermediate (P/I) browse										
Acacia spp.(8)(P)	85	33.1	65	9.4	32	14.2	10	4.0	192	13.5
C.gratissimus(P)	8	3.1	28	4.1	0	0.0	0	0.0	36	2.5
D.cinerea(P)	21	8.2	168	24.4	52	23.0	38	15.4	279	19.7
T.sericea(I)	1	0.4	21	3.0	44	19.5	131	53.0	197	13.9
X.americana(I)	0	0.0	1	0.1	0	0.0	0	0.0	1	0.1
Sub-total	115	44.7	283	41.1	128	56.6	179	72.5	705	49.7
Good browse										
A.erioloba	0	0.0	1	0.1	0	0.0	0	0.0	1	0.1
A.anthelmintica	0	0.0	15	2.2	0	0.0	0	0.0	15	1.1
B.albitrunca	12	4.7	20	2.9	1	0.4	4	1.6	37	2.6
C.mopane	28	10.9	0	0.0	0	0.0	0	0.0	28	2.0
C.imberbe	0	0.0	24	3.5	1	0.0	2	0.8	27	1.9
Grewia spp. (2)	68	26.5	261	37.9	79	35.0	25	10.1	433	30.5
L.nelsii	1	0.4	2	0.3	8	3.5	21	8.5	32	2.3
R.tenuinervis	15	5.8	42	6.1	8	3.5	0	0.0	65	4.6
Sub-total	124	48.2	365	53.0	97	42.9	52	21.1	638	45.0
Unidentified	18	7.0	41	6.0	1	0.4	16	6.5	76	5.3
TOTAL	257	100	689	100	226	100	247	100	1419	100

Bush control is often expensive or potentially damaging to the environment. For example the use of goats to control the growth of shrubs may result in desirable browse species being preferentially eaten, resulting in an increase in the competitiveness of undesirable species such as D. cinerea and certain Acacias. A method of locating and mapping areas of differing browse potential using satellite data would aid management decisions. It would also provide useful information at the reconaissance level when landuse plans are being established.

5.8 Estimation of woody cover using aerial photography.

5.8.1 Location of sample sites.

Aerial photographic data (1:50,000 scale, black and white; 13 - 16 May 1983), together with ground data and photographs (April - June 1983), was used to obtain estimates of the percentage cover of woody species throughout the Kalahari Sandveld zone. Selected sample sites were to correspond to a group of pixels on a Landsat image of the same month (7 May 1983, ID=40995-07551).

Originally, sites were selected by generating random coordinates and locating the position on 1:50,000 scale maps of the area. However, subsequent, accurate location of Landsat pixels was difficult and a different method was adopted. Blocks of four pixels (2 x 2) of similar reflectance response were selected where these formed part of, or occurred close to, an identifiable image feature. These image features correspond with ground features seen on aerial photographs. The blocks of four pixels were located visually, using an automatically contrast stretched colour composite (MSS bands, 4, 5, and 7). The column and row coordinates of the pixels were recorded, as were their reflectance values in the four Landsat MSS bands. The coordinates were later used to relocate the blocks of pixels once the imagery had undergone futher enhancements, for example band ratioing. This allowed the numerical values of the pixels to be recorded after these data transformations.

The pixel groups were located on the aerial photography using the image features previously identified, which correspond to visible ground features.

When selecting the original pixel blocks on the Landsat image, the screen cursor was positioned using the image column and row numbers and a pair of random numbers as coordinates, then the nearest suitable group of pixels was selected. This procedure introduced an element of randomness into an otherwise subjective selection of sample ´sites´.

5.8.2 Measurement of cover from aerial photographs.

The sample areas were located on the 1:50 000 aerial photographs (fig. 5.8), and were examined stereoscopically at x3 magnification. A single photograph was then placed under a binocular microscope, with overhead illumination, and viewed at x10 magnification.

Fig. 5.8 1:50 000 scale aerial photograph of part of the study area.

A clear grid overlay of 0.2 millimetre squares was placed over the sample sites on the photographs (the grid corresponded to 10 metre intervals on the ground). The grid provided 400 intersections or ´points´ per site. These intersections were used to make a ´point count´ measurement of the amount of woody cover present within each sample. The number of points which occurred over tree or shrub cover were recorded. This number was then expressed as a percentage of the total number of points, giving the percentage cover value for the sample.

Certain problems were anticipated in using the method presented above. At the 1:50,000 scale, small shrubs could not be individually identified (therefore no enumeration of trees and shrubs was undertaken for these sample sites), although trees and larger shrubs could be distinguished. Therefore, to identify woody cover, interpretation based on tone and texture of the photograph was made, aided by field data and appropriate ground level photography. Field experience of the study area was useful as an aid to air photograph interpretation. A study by Gisladottir (1983) shows that field experience can markedly increase the accuracy of interpretation of vegetation cover classes.

The black and white photography also had the disadvantage that varied features may have a similar tone and texture but not colour. Thus, two different features may be classified together on the basis of tone and texture alone. For example, in the Sandveld zone, large flat topped Acacia trees are found growing on the periphery of small rain pans. The pans and trees are often similar in tone to each other, on the photographs, and special care must be taken not to misclassify the pans as woody cover or visa versa. To a certain extent this problem was eliminated by examination of the sites under the stereoscope, before the point counts were made.

5.8.3 Comparison of 1:50 000 with 1:10 000 scale aerial photographs.

A comparison between the 1:50 000 black and white, and 1:10 000 colour (Kodak 2445 film) air photographs of a small part of the study area was made to test the accuracy of cover measurements made with the former. The colour photographs cover the area of Tsetseku ranch. The colour photography was flown a month after the black and white (16 June 1983).

The scale of the colour photographs did allow identification of individual shrubs of less than one metre in diameter, when viewed stereoscopically. The colour film also eliminates some of the problems associated with different features having similar tonal values.

For the purposes of field survey, a plant was defined as part of the shrub layer if it was between 0.5 to 3 m in height and about 1 m or more in diameter. At the scale of 1;10 000, using a stereoscope with x3 magnification, it was possible to identify all the shrub and tree cover at each site, using the above definition for ´shrub´.

Thirty-two sample sites were selected in and around Tsetseku Ranch. A number of these were coincident with ground survey sites visited during April, May and June of 1983. Cutlines, tracks and boundary fences were used to locate sample plots on both sets of photographs. A 0.2 mm grid was used for point sampling the 1:50 000 photographs and a 1.0 mm grid for the 1:10 000. These grids give the same size sample plot and number of points at both scales (200 m x 200 m plot of 400 sample points). The results for each of the sites is shown in table 5.8.

The results suggest that the use of 1:50 000 scale photographs to measure cover is acceptable. The largest differences can be explained as a result of some of the problems discussed above, for example sample number two included a rain pan which it was difficult to distinguish from parts of the canopy on the monochrome photograph, and was included in the cover measurement. Where higher percentages were found at the higher resolution, it was noted that small scattered shrubs (not identifiable at 1:50 000) were increasing the point score for cover.

A standard student t test was performed using the data for both sets of photographs. There was found to be no significant difference between the two sets of figures at the 95% level.

Table 5.8 Comparison of Percentage Cover Measurements using 1:10 000 and 1:50,000 Scale Aerial Photography.

Sample	% Cover 1:10 000	1:50 000	Difference
1	24.25	26.25	+2.00
2	20.75	25.75	+5.00
3	55.00	59.00	+4.00
4	23.25	24.75	+1.50
5	22.50	22.25	-0.25
6	25.25	25.00	-0.25
7	25.50	27.50	+2.00
8	72.25	71.50	-0.75
9	36.75	35.25	-1.50
10	27.75	31.75	+4.00
11	25.50	27.25	+1.75
12	22.00	24.25	+2.25
13	28.00	24.00	-4.00
14	16.00	19.50	+3.50
15	11.50	13.00	+1.50
16	26.50	20.25	-6.25
17	28.00	23.75	-4.25
18	21.25	17.75	-3.50
19	21.00	23.50	+2.50
20	23.25	19.75	-3.50
21	24.50	19.00	-5.50
22	12.25	14.00	+1.75
23	13.50	10.50	-2.00
24	11.75	10.50	-1.25
25	14.50	13.00	-1.50
26	16.25	17.00	+0.75
27	17.50	12.50	-5.00
28	15.75	13.50	-2.25
29	13.00	8.00	-5.00
30	13.50	12.50	-1.00
31	13.25	14.50	+1.25
32	19.75	19.00	-0.75
mean	23.18	22.69	+/-2.55

5.9 Analysis of the relationship between Landsat MSS data and woody cover.

Initially, 49 blocks of sample pixels were located on the May 1983 Landsat scene. The corresponding sites on the aerial photographs were found and the percentage woody cover values calculated. The mean reflectance value for each MSS band was calculated for the 49 samples. The mean values were regarded as corresponding to the ground reflectance conditions found within the sample sites located on the aerial photographs. Because there is a certain amount of overlap between neighbouring pixels on a single scan line, this results in nominal pixel size of 56 m x 79 m (versus the 79 m x 79 m area for which the reflectance data is actually derived by the sensor). Therefore, the actual area of reflectance measurement in the sample blocks is (2 x 79 m) x (2 x 79 m) less the amount of overlap (23 m) between neighbouring pixels on the scan line, resulting in an area of 158 m x 135 m. The area of the point count sample grid, which is used to measure the amount of woody cover, is equivalent to 200 m x 200 m on the ground surface (4 mm x 4 mm on the 1:50 000 aerial photography). The larger photograph sample size takes into account any error of location of the Landsat samples.

As well as the individual MSS band values, a number of enhancement procedures were carried out on the image sub-scenes containing the sample sites. The new values based on the enhancements, for each of the sample sets of pixels was recorded and the mean values calculated. The enhancements included a number of band ratios based on the visible red, chlorophyll absorption, waveband (MSS band 5), and the near infra-red waveband (MSS band 7), which is highly reflected by healthy green vegetation. These included the simple ratio of 7/5, as well as more complex ratios such as the normalised difference vegetation index used by Lane (1982). A Principal Components Analysis of the scene data was also carried out and the values of the sample pixels recorded in the first four principal components. All the enhancements were undertaken using the DIAD image processing system.

The calculated mean values for the sample pixel groups (individual band values and the results of enhancements), were then compared with their corresponding values for percentage woody cover. Scatter diagrams were plotted with percentage woody cover as the independent variable (x) and the various reflectance values as the dependent variable (y). The relationship between the percentage woody cover (x) and the dependent variables (y) was tested using the Pearson product-moment correlation coefficient (r).

The strength of the relationship between the variables was ranked on the basis of the correlation coefficient (r) and is given below (table 5.9). The highest correlation (r = -0.94) was calculated for percentage woody cover against the individual MSS band 5 values for the 49 samples (fig. 5.9).

It is interesting to note that, excluding the first principal component (ranked third), the strongest correlations between percentage woody cover and the Landsat data variables, is with the individual MSS band values. All of these values

Table 5.9 Relationship between percentage woody cover (x) and Landsat reflectance values (y).

The Landsat reflectance values (y) are ranked in descending order on the basis of their caculated correlation coefficient with values for percentage woody cover. All figures based on 49 sample sites.

Rank	Variable (y)	corr. coefficient (r)	Standard error of estimate.
1	MSS 5	- 0.94157 *	7.12
2	MSS 4	- 0.93249 *	4.61
3	1st. Principal component	- 0.93217 *	5.25
4	MSS 7	- 0.92194 *	5.10
5	MSS 6	- 0.91805 *	6.46
6	MSS 7 + MSS 5	- 0.90790 *	14.46
7	MSS 7 - MSS 5	- 0.88400 *	4.31
8	MSS7 + MSS5 / MSS7 - MSS5	- 0.84822 *	3.56
9	MSS 7 / MSS 5	+ 0.84433 *	6.08
10	MSS7 - MSS5 / MSS7 + MSS5	+ 0.82896 *	3.91
11	2nd. Principal component	+ 0.21875	14.56
12	3rd. Principal component	+ 0.13998	1.21

* = significant at the 99.9% level.

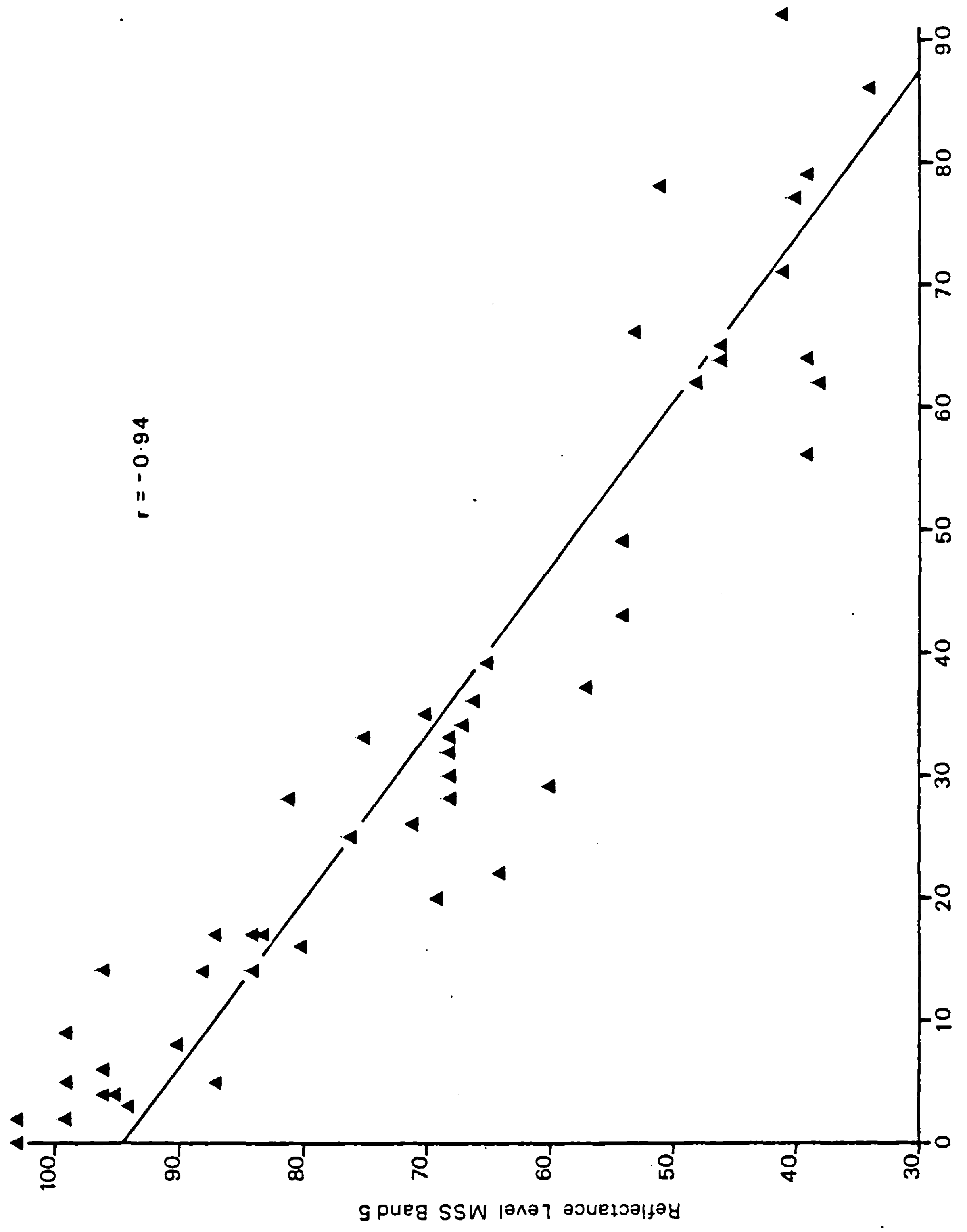


Fig. 5.9 Scatter diagram showing the relationship between percentage woody cover and MSS band 5 values.

have a strong negative correlation with the cover data. This negative relationship was expected for certain of the MSS bands, because of the very highly reflective nature of the soils of the Kalahari Sandveld terrain, in contrast with the responses from vegetative cover.

MSS band 5, the highest ranking of the Landsat data variables, records reflectances in the visible red light section of the electromagnetic spectrum and includes a peak of high absorption (by chlorophyll) at about 0.65 um. Therefore, where green woody vegetation cover is high, the MSS band 5 values will tend to be low, while areas with low woody cover and high amounts of exposed, highly reflective sandy soils will have high response values. A similar negative relationship had been found, by Griffiths and Collins (1983), for MSS band 5 values and non-green woody cover. However, their correlation between the two variables ($r = -0.6$) was not as strong as that found for green woody cover ($r = -0.94$). This is not totally a result of differences in the response of non-green and green woody vegetation to visible red light. The strong negative correlations between cover and other MSS bands which are associated with high reflectances from green vegetation (MSS bands 6 and 7), indicates that, although chlorophyll absorption may increase the contrast between woody cover and bare soil, the relationship is a more general one, which includes all of the Landsat wave-bands. Differences in the results between the two studies may be the result of both environmental factors and sampling procedures. The Kenyan study was in an area of lower average rainfall (< 150mm) than the Botswanan study, with a vegetation of dwarf shrub grassland and 'bushed' grassland (characterised by Acacia reficiens) and predominantly sandy/silty soils. Green vegetation at the time of Landsat data acquisition for Kenya (June 1979) was thought to be restricted to the herbaceous layer. However, the lower rainfall conditions might be expected to produce conditions which would increase the contrast between the response of bare soil and woody cover, rather than lessen this. Because of the importance of the soil response in the relationship under investigation, differences in soil factors such as colour and texture may play an important role in the variation within the Kenyan data. Griffiths and Collins (1983) also state that their "...survey to collect ground-data was flown two years after the date of the latest available Landsat scene ..." and although they "...assumed that the ground cover had not changed substantially during the two intervening years of near normal rainfall.", this difference in the timing of the data may have influenced the results.

It has been noted that the other individual Landsat bands (MSS bands 4, 6 and 7) are often associated with 'peaks' of reflectivity in the spectral responses of green vegetation. MSS band 4 (visible green light) is generally associated with a slight peak at about 0.54 μm (see fig. 2.1). MSS band 6 is associated with the steep increase in reflectivity of green vegetation (the 'red edge') in the near infrared wavelengths, reaching a peak in the range of MSS band 7 (0.8 to 1.1 μm). Although these peaks in response occur in the spectral response curve of green vegetation, it has been noted that in regions of low rainfall, "...the reflectance from very dry highly reflective soils can be higher in the near infrared than for vegetation." (Allen and Richards, 1983). This is in contrast to more humid areas, where vegetation response in the infrared wavelenghts is usually much higher than that for soils (because of absorption of infrared wavelengths by moisture in the soil). Thus in arid and semi-arid zones, higher vegetation cover may actually produce lower infrared reflectance values than those obtained from low vegetation cover with a large area of exposed soil surface. This certainly appears to be the case in the Kalahari Sandveld terrain zone, where high infrared values are associated with low percentage woody cover values.

The values of the first principal component (which accounted for 89.53% of the variation in the original four band data set), appear to represent 'image brightness' of the original data. As described above, image values within the sandveld terrain tend, for the four MSS bands, to be highly correlated. High vegetation cover resulted in low MSS values and low cover produced high values in all bands (the lowest correlation between MSS band values for the 49 sample values was r = 0.95 for MSS bands 4 and 6, the highest was for the two infrared bands, r = 0.99). This strong positive correlation between within the Landsat data produces a major axis in the data based on increasing reflectance levels, represented by the first principal component. Therefore, the first principal component would be expected to give a strong negative correlation with percentage woody cover.

Because of the strong positive correlations between the Landsat MSS band values of the sandveld zone imagery, the band ratios tested also show strong relationships with the values for woody cover. One of these ratios (7/5) was the variable ranked as having the most useful relationship with woody cover by Lane (1981). This ratio was ranked ninth in the present study, but still showed a strong correlation ($r = 0.84$) when compared to the result obtained by Lane ($r = < 0.22$). Lane ranked MSS band 5 as the third most useful variable.

It appears that in the case of the study area (Kalahari Sandveld terrain) woody cover (in the absence of an significant herbaceous ground layer vegetation) is inversely related to the recorded reflectance values in the range 0.5 to 1.1 μm (the range of the Landsat MSS system). This appears to be connected with very high reflectance values typical of dry, light coloured soils in arid and semi-arid zones and the relatively lower response values of the vegetation typical of these climatic types. Because of the role of visible red light in the photosynthetic process (hence high absorption by green plant material of this section of the spectrum) the MSS band 5 values provide the best (negative) correlation with percentage woody cover. The parts of the woody plants which do not form photosynethetic organs (and lack chlorophyll) will also tend to produce lower reflectance values than the soil surface (as demonstrated by Griffiths and Collins (1983)) and therefore contribute to the effect. The reflectivity of different species of woody plant may vary, depending on factors such as leaf shape, size and pigmentation, whether the plant is healthy or stressed, and the colour and texture of bark. However, the results from the sample sites (which cover the different vegetation types of the sandveld area and include a number of sites within the fringe woodland, of the riverine zone terrain type) suggests that species differences do not greatly affect the relationship between reflectance values and (green) woody cover.

5.10 Classification of woody cover.

5.10.1 Introduction.

Having obtained the results of the correlation analysis, which described the degree of the relationships between the woody cover data and the various Landsat data variables, the form of the relationships was calculated using a best fit linear regression (STATISTICS option, within the SPSS and SPSS-X SCATTERGRAM commands (SPSS inc., 1983)). Regression lines were fitted to the bivariate plots (of percentage woody cover (x) against the Landsat variables (y)) using the calculated values for the y axis intercept (c) and the slope (m) in the equation;

$$y = mx + c$$

The regression provided a mathematical model of the relationship between the cover data (x) and the spectral response variables (y), which could be used as a predictive tool. The regression statistics were used to calculate (predict) the Landsat data values corresponding to specific values of the independent variable, woody cover (see fig. 5.9). This provided the basis for a classification of the Landsat imagery into classes of varying percentage woody cover (see below). The results of the predictions were 'rounded' to the nearest whole number to conform with actual Landsat data values.

The regressions were also used to predict spectral response curves for various values of woody cover. The spectral response values of five of the original 49 samples were predicted and compared with their actual response values in each Landsat MSS band. The samples used were chosen to represent intervals of approximately twenty percent in terms of woody cover values, from very low values (6%) to very high values (86%). Figure 5.10 shows the nature of the spectral response curves for both the actual and the predicted MSS values.

The two sets of curves are broadly similar, both showing a distinct change in the nature of the curves between low and high values of woody cover. All the MSS band values increase with decreasing cover values (as expected from the results of the correlation analysis). The range of the MSS values in each band, between the highest and lowest cover values, is very similar for the predicted and actual values. This range is greatest for MSS band 5 (with a range of brightness values of 62 and 61 for the actual and predicted curves respectively). The response curves for the high vegetation cover values conform to 'typical' response curves for vegetation within the spectral range of the Landsat sensors

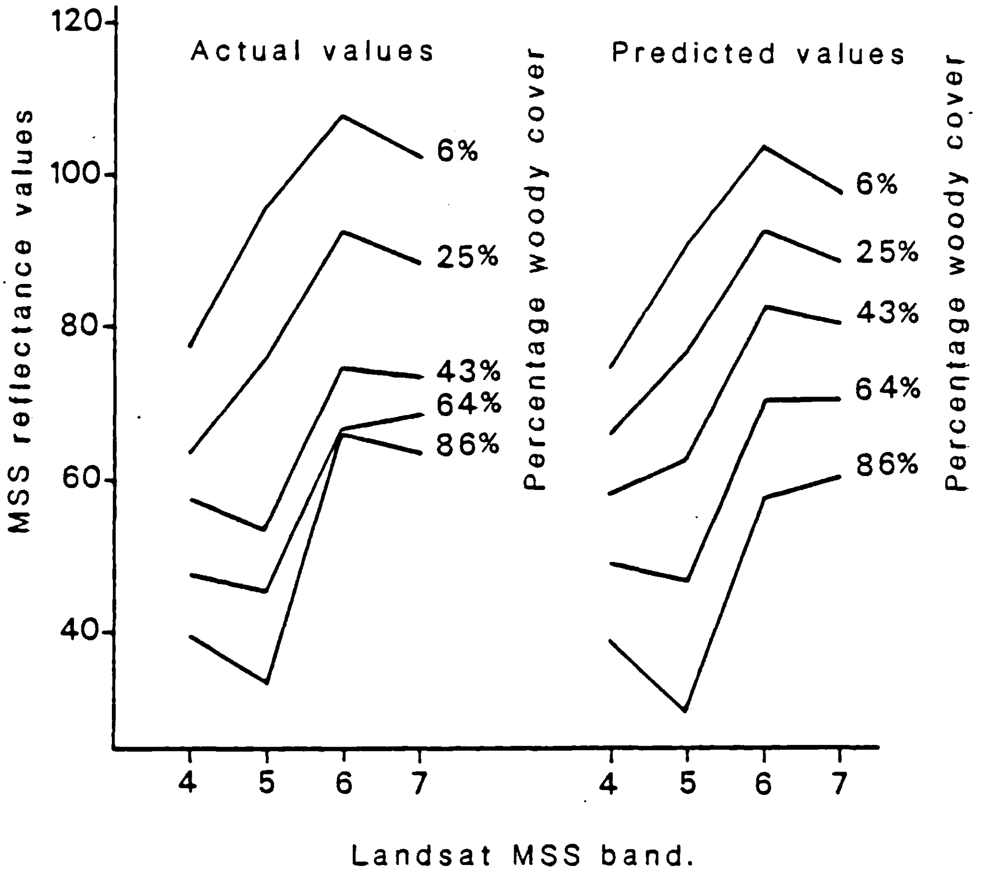


Fig. 5.10 Spectral response curves for various values of percentage woody cover.

(fig. 2.1). The curves show the typical green reflectance peak in MSS band 4, chlorophyll absorption leading to low MSS band 5 reflectance levels, and the large peak in reflectance values in the two, near infrared bands.

The curves for areas of very low woody cover do not have this typical form, but show increasing reflectance values from MSS band 4 to a peak in MSS band 6, with a slight decrease in MSS band 7 values. Increasing reflectance levels, from the shorter to longer wavelenghts, is typical of the response curves of soils. Soil curves tend to be similar in shape even with large variation in soil types, varying mainly in the amplitude of the curve (Hoffer, 1978), (amplitude is affected by factors such as, texture, colour, moisture and organic content). The decrease in MSS band 7 values is not ′typical′, but is fairly small and the curves may reasonably be described as conforming to the reflectance characteristics of soil. A decrease in MSS band 7 values relative to MSS band 6 values may also be seen in a bivariate scatterplot published by Griffiths and Collins (1983) for sites with very low vegetation cover and high amounts of exposed soil surface. The shape and amplitude of the curves for the areas of low woody cover are consistent with the probable reflectance responses of the dry, sandy, pale coloured soils encountered within the Kalahari Sandveld terrain type.

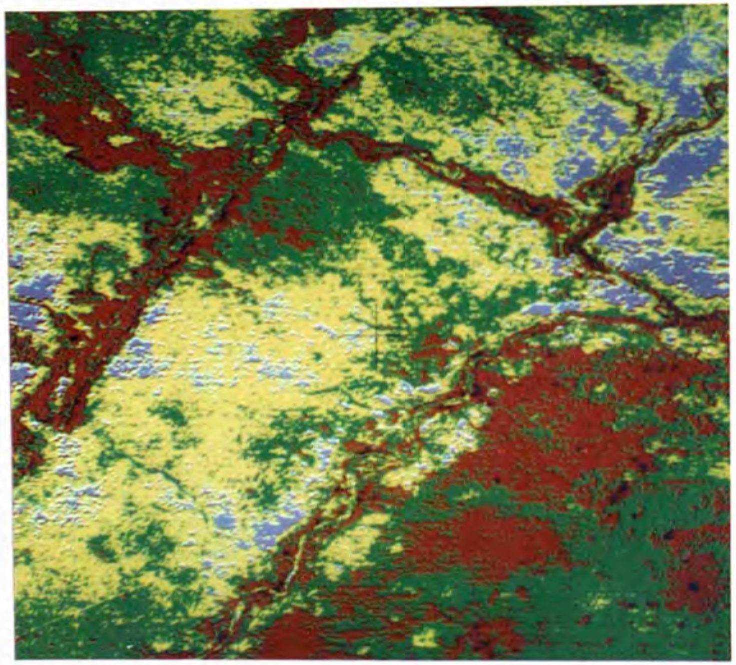
The form of the spectral response curves (both actual and predicted), tends to confirm the view that the relationship between woody cover and the Landsat variables is based on changes in the areal extent of two main ground surface components, woody cover versus exposed soil surface.

5.10.2 Classification procedure.

The results of the regression analysis (described above) were used to calculate the predicted MSS band values (y) for a number of classes of the independent variable (x), percentage woody cover. Table 5.10 shows the class ranges for two of the Landsat MSS bands and for the first Principal Component values calculated from the data for all four MSS bands (section 3.4.2).

The ranges calculated for given classes of woody cover were then used to classify a Landsat sub-scene containing areas of the Kalahari Sandveld terrain. The sub-scene was displayed, on the colour monitor of the DIAD image processing system, as a single band grey-scale image. Classification was achieved by 'density slicing' (see section 3.4.2) the grey-scale data into classes. The upper and lower limits of each of the calculated ranges were entered, all pixels found within a given range were then displayed in a uniform colour on the monitor screen. Density slicing provided an effective means of grouping the large number of data points (pixels), that make up a subscene, into classes.

Figure 5.11 shows a sub-scene which has been classified by density slicing a grey-scale image of MSS band 5. The sub-scene shows the junction of the Boteti and Thamalakane rivers, and includes the area in which many of the 49 sample sites are located. The boundary of the Kalahari Sandveld terrain type represents the limit to which classification can



Percentage woody cover

0 - 19% Magenta 40 - 59% Green

20 - 39% Yellow 60 - 79% Red

> 80% Black

Fig. 5.11a Classified image showing percentage woody cover classes, Kalahari Sandveld.

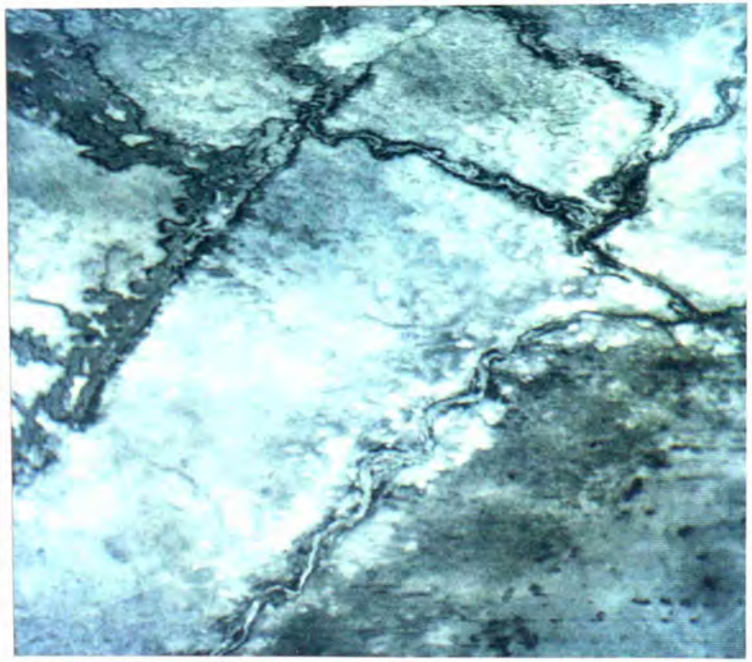


Fig. 5.11b MSS band 5 image of the classified Kalahari Sandveld area.

Table 5.10 Class ranges for woody cover classification using Landsat data.

Class	Cover interval (%)	Range of Landsat data variables (brightness value)		
		MSS 4	MSS 5	1st.P.C.
A	80 - 100	<42	<36	<53
B	60 - 79	42 - 50	36 - 50	53 - 63
C	40 - 59	51 - 59	51 - 65	64 - 73
D	20 - 39	60 - 68	66 - 80	74 - 83
E	19 - 0	>69	>80	>83

be confidently extrapolated, this is indicated on the classified image. Areas beyond this terrain type represent different environmental conditions where the classification may not be applicable. A number of the original sample sites were located in areas of riverine fringe woodland which is regarded as part of the Riverine Zone terrain type (section 4.8.2(b)), but which shares similar soils conditions with the Kalahari Sandveld being above the general level of seasonal flooding. The significance of the results of the correlation analysis suggests that this component of the Riverine Zone probably acts very similarly to the Kalahari Sandveld area in terms of reflectance responses and the relationship with woody cover. The fringe woodland contains a mixture of woody species, some of which are found in the neighbouring sandveld and some which are not.

It is possible that the classification is also applicable to the Mopane Sandveld terrain type. The Mopane Sandveld sites had soil surface conditions similar to those of the Kalahari Sandveld (see chapter VI). The surface soils of both areas were fine grained sands, usually very pale in colour.

The areas of molapo and open water which occur in the classified subscene are totally misclassified as areas of high percentage woody cover. These areas could be masked off in any final classification. The misclassification of these areas as high cover values, is the result of high absorption of visible red light by both water and the relatively healthy green grasses which are able to survive in the floodplains.

The woody cover and MSS values of the 49 samples were used to provide an initial assessment of the accuracy of the classifications attempted. The number of sites which were correctly classified within the predicted ranges were divided by the total number of sites (table 5.11).

To further test the accuracy of this form of classification, twenty more sample sites were located on the MSS band 5 classified image. Five groups of four pixels were located in each of the classes B to E (most representative of the Kalahari Sandveld) and then located on the 1:50 000 scale aerial photographs. The point count method was used to estimate the percentage woody cover of the new samples. The overall accuracy was calculated for this group of samples, remained close to that of the original samples at 80%, four of the twenty samples being misclassified. Table 5.12 indicates the separation of the classification feature space for both sets of samples combined (69 samples), showing errors of omission and commission. The overall accuracy of the classification based on the combined figures is 79.7%.

The misclassified pixel groups (approximately 20% of the samples) were all classified into the class neighbouring that into which they should have been classified. These errors of classification may have been caused by a number of factors, including statistical, instrument and human factors, as well as enviromental.

Table 5.11 Overall accuracy of classifications of percentage woody cover.

Classification (Landsat variable)	No. of sites correctly classified	Percentage accuracy of classification
MSS band 4	33	67.3%
MSS band 5	39	79.5%
1st. P.C.	36	73.5%

$$\text{Overall accuracy} = \left(\frac{\text{No. of correctly classified sites}}{\text{Total No. of sites}}\right) \times 100$$

Table 5.12 accuracy of the classification of woody cover based on Landsat MSS band 5 data.

Class pixel was assigned to in feature space (Percentage woody cover).

	>80%	79-60%	59-40%	39-20%	<19%	Errors of ommission
100-80%	0	2	0	0	0	2
79-60%	0	12	3	0	0	3
59-40%	0	1	6	1	0	2
39-20%	0	0	4	17	1	5
19-0%	0	0	0	2	21	2
Errors of commission	0	3	7	3	1	55 **

$$\text{Overall accuracy} = \left(\frac{55}{69}\right) \times 100\ \% = 79.7\%$$

** Sum of the principal diagonal.

Environmental factors which may lead to misclassification are similar to those described in the section on estimating woody cover from aerial photography. Ground features, other than the two main components (woody cover and exposed soil), will have an affect on the spectral response of single or groups of pixels. For example, accumulation of olive grey clay in the central parts of rain pans would tend to cause a decrease in the reflectance values of what might otherwise have been exposed sandy soil, and result in the area being classified as having higher levels of woody cover than actually occur. The presence of a rain pan would affect the classification similarly, which ever MSS band was used, as the dark colour of the clay would depress the response levels across the whole range of values.

Misclassification may be influenced by statistical factors. The 'rounding' of figures at various stages in the analysis and classification procedure may influence the final classification. The statistical tests themselves are also important, for instance the regression analysis is a 'best fit' procedure, and as such the resulting regression line on which the classification is based is unlikely to fit all the possible cases within a large population of data. This will be especially true where a complex natural environment is being investigated.

Instrument errors, such as the miscalibration of one of the six sensors used to record each MSS band, could cause data values to be offset sufficiently, relative to neighbouring lines, to affect the classification. Instrument errors are often noticeable on the pre-classification imagery, however, image correction procedures (section 3.4.1) are purely cosmetic and do not represent the true reflectance response of the corrected pixels. Data problems often becomes more noticeable after an image has undergone particular enhancements, density slicing often enhances any 'banding' in the data. No major data errors were detected at any stage during the analysis of the May 1983 imagery, however, small differences in instrument calibration may affect the classification of pixels at the boundary between classes.

Human errors may occur at a number of points during the sampling, analysis and classification procedures. Errors may be minimised as much as possible by rechecking results at each stage of the process (see sections dealing with aerial photograph analysis (section 5.8), ground investigation and sample site selection (sections 5.5 and 5.6)).

The correlation and regression analyses were also re-run with the additional twenty sample values. There was little change in the overall results. In the case of MSS band 5, which was used for the classification, the result of the correlation analysis was very little different from the original (69 samples $r = -0.94224$). The recalculated regression statistics were not sufficiently different to alter the predicted values used in the classification.

Given the nature of the terrain under investigation, classification accuracy of about 80% can be regarded as useful. The method provided a relatively fast method of mapping woody cover over large areas, which were often poorly accessible on the ground. Complementary data sources are essential for establishing the relationships between the remotely sensed data and the actual ground features, however, these other data sources would not have been sufficient in themselves. A classification based purely on ground and/or aerial photographic data would be extremely time consuming and difficult to implement over large areas. Higher resolution multispectral data, for example from an airborne scanner system, would not necessarily provide greater accuracy, the type of problems outlined above would still pertain and such a survey would probably be economically infeasible for large areas of extensive rangeland in Africa.

5.10.3 Classification of the Tsetseku ground survey area.

The woody cover classification (based on MSS band 5 data) was applied to imagery of the Tsetseku area, to allow detailed examination of the uses of the method as a rangeland management tool. To facilitate examination, the image data was geometrically corrected. The correction was based on the 1:50 000 scale topographic map series. The correction procedure available on the DIAD image processing system was used.

Geometric correction of the image data has a number of implications for the subsequent classification and examination of the data. The important points of the procedure are therefore briefly outlined below, a detailed description of the procedure is given in the DIAD users manual (Nigel Press

Associates, 1983).

The image to map registration procedure involved two main stages. Firstly, the interactive selection of ´control point´ data and specification of the ´resampling parameters´ to be used. Secondly, resampling of the image data and the conversion of the ´raw image´ to the desired geometry (in this case the ´reference geometry´ of the 1:50 000 scale topographic maps).

The correction was based on a number of selected ´control points´, features which could be accurately located on both the raw image and the chosen ´reference geometry´ (the topographic map). As the topographic maps were based directly on aerial photograph mosaics (photo-maps), aerial photographic material was used as an aid to control point selection. Control points were located and their positions typed into the DIAD system. Image positions were given as line and column numbers, and the reference geometry positions as coordinates based on a rectangular grid of 0.5 cm squares which was overlaid on the map. Features regarded as remaining fairly stable through time were used as control points (the map series was based on an aerial survey conducted in 1969). The 1:50 000 aerial photographs acquired in 1983 were used to confirm the stability of features located on the map. Control points chosen included features such as road and track junctions, fence lines and certain natural features which appeared to have remained static (river bends, island edges in the molapo areas). The accuracy of each control point was determind by the correction program itself (the least squares error is calculated) by reference to all the previously selected points. This allowed control points to be rejected if they appeared grossly erroneous (including checking of points chosen early in the procedure).

The area of interest on the Tsetseku sub-scene was relatively small. Fifteen control points were selected as the basis for the correction, a minimum of 20 control points is suggested for the correction of a whole Landsat image. The two sets of values are then submitted to a least squares regression analysis to determine the coefficients for the transformation equations that interrelate the reference geometry and the raw image. The transformations are then applied to the raw image by a process know as 'resampling'. A matrix is defined in terms of the reference geometry (output matrix). The computer determines the coordinates of the raw image that correspond to each cell of the output matrix, the appropriate pixel values are then transferred to the output matrix. The cells of the output matrix do not precisely match individual image pixels. A number of solutions are available to solve this problem, for example, simply allocating the values of the pixel closest to the matrix cell (nearest neighbour resampling). In the case of the Tsetseku image, a more sophisticated resampling procedure was used, 'bilinear interpolation'. This method uses a proximity-weighted average of the four pixels nearest to the output cells. This method does in effect create new pixel values rather than simply transferring values from a single pixel to a single output cell. The method generated an image of smoother appearance than the original raw image, this has been noted as characteristic of this type of resampling (Lillesand and Kieffer, 1979). In the present case, the cell dimensions of the output matrix were defined as 50 m x 50 m, slightly smaller than the original raw image pixel size.

Changes in the pixel dimension and reflectance values during resampling will affect analysis of the imagery. In the present study it was possible to maintain the sample dimensions used to measure woody cover from aerial photography, as the pixel size was reduced slightly. The changes in pixel values caused by resampling may, however, have caused some important changes in the imagery used for classification (these are discussed in the context of the results of the analyses described below).

The ´corrected´ image (fig. 5.12) was still slightly distorted (most noticeably when looking at the angle of intersection of fencelines at Tsetseku), however, the comparability of the image with the topographic map and the aerial photographs was improved. The location of subtle ground features was generally made easier, although the smoothing effect of the resampling procedure did result in the boundaries between certain image features becoming less clear.

The classification developed for woody cover was then used to classify the geometrically corrected image. The class interval sizes were decreased to give six classes representing ten percent increments in woody cover (0-9%, 10-19%, 20-29%, 30-39%, 40-49%, 50-59%). A ´dump´ class for all areas

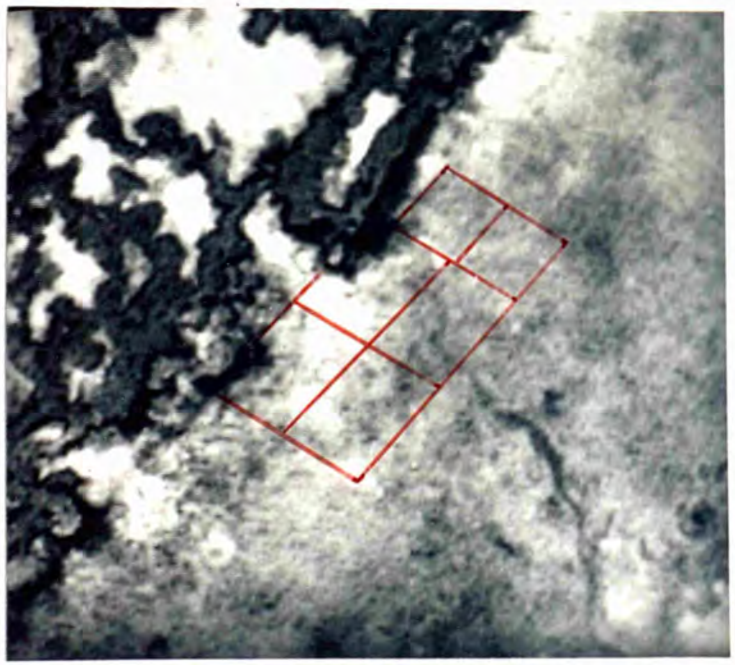
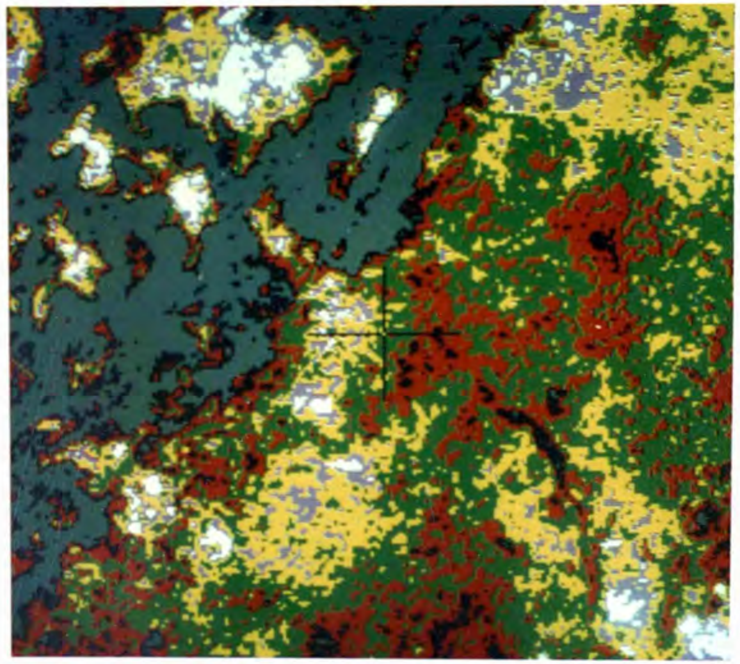


Fig. 5.12 MSS band 5 image of the Tsetseku Ranch area.



Percentage woody cover

0 - 9% White
10 - 19% Magenta
20 - 29% Yellow
30 - 39% Green
40 - 49% Red
50 - 59% Black
>60% Grey

Fig. 5.13 Classified image showing percentage woody cover classes,Tsetseku Ranch area.

classified as 60% or more woody cover was also included. The six decile classes contain the range of cover values which are found in the Kalahari Sandveld terrain's low tree and shrub savanna (section 5.7.3).

The MSS band 5 values corresponding to the new class intervals were calculated from the regression statistics. Because of the need to round the calculated values to whole numbers to correspond to the grey-scale values of the image data, the range of values per class alternated between seven and eight. The affect of this on classification accuracy is discussed below.

Figure 5.13 shows the classified image of the Tsetseku area. The position of the ranch fencelines and the main route-ways are visible where these have had an effect on the distribution of vegetation cover (for example, the boundaries between areas of controlled and common grazing). An indication of the east - west orientation of ground features (related to the ridge and depression topography) is visible in the pattern of woody cover. The pattern of the woody cover classes appears to correspond to some degree with the distribution of the main vegetation types at Tsetseku (see fig 5.3). Given the significant differences found in the levels of percentage woody cover between these vegetation types, some similarity in these patterns is expected. The large zone of Terminalia sericea dominated vegetation, which crosses paddock 4 of the ranch, is clearly visible. The distribution of areas of low percentage woody cover also corresponds well to the pattern of Acacia dominated depressions.

The accuracy of the classification at the decile class level was tested. A random sample of classified pixels (in groups of four) was collected, their image coordinates, MSS band 5 values and the class into which they were classified were noted. The sample sites were located on aerial photographs (1:50 000 scale) and a measure of their percentage woody cover made by point count (the same sample size was used as before (section 5.8.2)). Of the sample of 45 pixel groups, eleven were misclassified. Table 5.13 shows the separation of the samples within the classification feature space. The overall accuracy of the classification, as calculated from the sample, was 75.6%.

A decrease in the accuracy of the classification was expected for the new class intervals. However, compared to the overall accuracy of the original classification, it amounts to a decrease in accuracy of less than 5%. In order to compare the accuracy of classification of the original raw image data with that of the geometrically corrected data, the six decile classes were combined to form three classes of twenty percent intervals (corresponding to classes C, D, and E of the original classification). This resulted in an increase of 6.6% in the accuracy of classification of the 45 samples for the geometrically corrected image, to 82.2% (table 5.14).

An increase in the overall accuracy of the classification of slightly over two percent, between the raw image data and the geometrically corrected data cannot be regarded as significant. It does confirm the level of accuracy of the method at about the 80% level. A small increase in

Table 5.13 Accuracy of the classification of woody cover

(Tsetseku area sub-scene. 10% interval classes).

Class pixel is assigned to in feature space (percentage woody cover)

	59-50%	49-40%	39-30%	29-20%	19-10%	9-0%	Errors of ommission
59-50%	5	1	1	0	0	0	2
49-40%	0	6	3	1	0	0	4
39-30%	0	2	9	1	0	0	3
29-20%	0	0	1	7	0	0	1
19-10%	0	0	0	1	3	0	1
9-0%	0	0	0	0	0	4	0
Errors of commission	0	3	5	3	0	0	34 **

$$\text{Overall accuracy} = \left(\frac{34}{45}\right) \times 100 = 75.6\%$$

** Sum of the principal diagonal.

classification accuracy may possibly be attributed to an improvement in the location of sample sites between the corrected imagery and the aerial photographs. The smoothing effect of the resampling procedure used to achieve the correction does not seem to have affected classification accuracy. However, when compared with the same classification performed on the raw image of the Tsetseku area, it is apparent that the smoothing does have an effect on the visual display of the classification, areas on the image appear more homogenous, with fewer individual pixels classified differently from areas dominated by a particular class of cover values. The resampling has had the effect of smoothing out unusual fluctuations in the general response levels of areas on the imagery, thus localised patches of higher or lower cover creating a 'peak' or 'trough' in the general data will tend to be lost in the geometrically corrected image. The averaging effect of the bilinear interpolation resampling method therefore produces a slightly more generalised view of ground conditions without affecting accuracy. This affect may actually be beneficial in terms of mapping in areas of extensive rangeland, the occurrence of small patches (a few pixels or less in size) of anomalous cover values within a generally more uniform area may not be of interest and be regarded as 'noise' in the data.

The applications of the classification in its present form, for rangeland management and landuse planning purposes, would include the planning of bush control programmes, monitoring the encroachment of woody vegetation, and the allocation of range resources on the basis of grazing potential. The results suggest that successful monitoring would be dependent on the acquisition of adequate support data to check the accuracy of the classification at the time of Landsat data acquisition. The use of non-contemporary data sources is open to problems of comparability which may be difficult to overcome when trying to make a quantitative assessment of change. The need for good support data is also essential to exporting the classification to a different geographical location. Slight differences in environmental conditions may not affect the basic relationship between woody cover and the MSS data, but the precise form of the relationship is bound to change.

Comparison of the classified image of Tsetseku (fig. 5.13) with the vegetation patterns seen on the aerial photographs and from ground survey (see fig.5.3), indicated that the classification could possibly provide a method of identifying the distribution of the main vegetation types at Tsetseku. This would provide other information useful to range management, on general species composition and browse potential. The detailed ground survey at Tsetseku showed that the relative value of the main vegetation types, in terms of browse value, varied markedly. The average number of woody plants of good browse value varied from 53.0% of the total (per unit area) in the areas of mixed species savanna to only 21.1% in areas dominated by Terminalia sericea (a poor browse species), (see table 5.7).

Analysis of the woody cover values of the main vegetation types showed a that a significant difference (at the 99.9% level) existed between them. An attempt was made to use the characteristic cover values of the vegetation types as a means of mapping their general distribution. The highly significant correlation found to exist between the four Landsat MSS bands for pixels within the target area of the Kalahari Sandveld, meant that a more sophisticated classification of the vegetation types using multispectral data would not be appropriate. Three classes were selected based on the calculated characteristic cover values for the vegetation of the Acacia dominated depressions, the mixed species low tree and shrub savanna, and the Terminalia sericea dominated low tree and shrub savanna. The range of cover values which were to represent a particular class were derived from the calculated standard deviations from the mean cover value of each vegetation type. The overlap between the sample populations was such that the first standard deviation, above and below the mean value for cover, provided the optimum cut-off between the classes in terms of the calculated MSS band 5 values used (table 5. 5).

Because Landsat MSS pixel values are whole numbers, level 67, which falls between two classes, was not included in a class. On the basis of using the standard deviation to define the ranges, approximately 68% of the pixels in each of the resultant classes could be expected to be correctly classified.

The classified image produced by the above method did not compare very well with the pattern of vegetation distribution obtained from the aerial photography. Although the cover values of the different vegetation types may be significantly different in statistical terms, the populations overlap sufficiently to obscure the pattern of the vegetation in terms of the MSS data. The method does provide a rough indication of the general distribution of the main vegetation types, but its use as an indicator of browse potential would be limited to broad scale reconaissance survey level. Visual analysis of the imagery of this area at different times of the year (and in years of varied climatic conditions) through the 1970's, indicates that differences in spectral response between the vegetation types may not have been at their optimum in May 1983 (section 4.8.2(f)). The conditions which were ideal for establishing a useful relationship between Landsat MSS data and woody cover, are not necessarily the best for others. Analysis of the imagery indicates that summer (wet season) imagery may provide the best discrimination between the vegetation types, although the the presence of herbaceous layer vegetation may complicate the situation.

5.11 Discussion of results.

5.11.1 Introduction.

The results described in this chapter indicate the use and potential use of the Landsat MSS data and computer aided image analysis and classification as a data source and tools for particular aspects of rangeland evaluation and management.

The study also highlighted the importance of the type and timing of the supplementary data sources used; firstly, with regard to establishing the relationships between the remotely sensed data and ground conditions, secondly, in terms of the accuracy of classifications based on ground and aerial survey data. The importance of understanding the environmental factors specific to a particular target region or landscape type were discussed.

5.11.2 Relationship between Landsat MSS data and woody cover.

The relative success of the method developed to classify the distribution of varying amounts of woody cover was dependent on establishing a useful relationship between the satellite data and the corresponding ground conditions. The successful identification of a useful relationship appears to have been promoted by a number of related factors. The importance of some of these factors can be suggested by comparison with the results of other studies that looked at woody cover (Lane, 1982; Griffiths and Collins, 1983).

a) Selection of the target area. The present study restricted sampling, and the subsequent classification based on the sampling, to a target area (terrain type) previously identified as a unit of the landscape displaying some internal consistency (chapter IV). Once the controlling relationships for the desired classification had been defined, the possible application of the classification in other terrain types could be assessed (see chapter VI).

b) Timing of supplementary data collection. The present study was based on a hierarchy of data, acquired within a limited time period (1;50 000 aerial photographs and Landsat image, May 1983; 1:10 000 aerial photographs, June 1983; ground survey data, April-June 1983). Therefore, unlike the work of Griffiths and Collins (1983), problems associated with the comparability of data sources acquired at different times was not a problem (section 5.9). Both the classification of woody cover and the attempt to classify the main vegetation types at Tsetseku, show the need to take seasonal factors into account. The woody cover classification was successful because it was based on data acquired at the period of minimal grass cover in the sandveld areas.

c) Supplementary data. The hierarchy of data used in the present study improved the accuracy of sample site location and allowed cross checking of sampling procedures, for example, the use of the limited large scale aerial photographs (1:10 000) to check the accuracy of the measurements of woody cover made from the 1:50 000 photographs. The availability of data at scales intermediate to that of ground survey and satellite data, provided a substitute to establishing very large ground survey sites in an area of poor access and difficult terrain conditions (section 5.5).

d) Data sampling. In order to establish the relationships between satellite data variables and specific ground features/conditions, an adequate level of support data (ground survey and/or aerial photographic data) must be available. Lane (1982) attempted to establish relationships with only a small number of samples for a number of varied areas of vegetation and soil conditions (section 5.9). His results showed little correlation between the satellite data and ground conditions. In contrast, the present study was based on a larger sample set. The adequacy of the size of the sample was confirmed by the results obtained from subsequent check sampling of the classifications (these gave very similar results to those of the initial sample (section 5.10.2)).

It must be noted that temporally contiguous data sets, at a several scales of resolution, are often unavailable in developing countries such as Botswana. Therefore, the conclusions discussed above are not a criticism of other studies on these points. However, it does point to the need to integrate the planning of data acquisition, if satellite data is to provide a useful tool for resource evaluation in developing countries.

5.11.3 Accuracy of classification.

The apparent success of the method, described in this chapter, of classifying woody cover, was also seen to depend on a number of specific features of the Landsat MSS system.

a) The repetitive coverage of Landsat data (and the fact that the target area was within range of a ground receiving station during the possible dates for ground survey), meant that the acquisition of good quality data at a specific time was highly likely (in the event several images were available for the period of the ground survey in 1983). It also provided the opportunity to time the ground survey to coincide with optimal ground conditions, without being restricted to a particular period of satellite data acquisition. This was important in the present study, where specific vegetation conditions were essential to the success of the classification method.

b) The resolution and the areal coverage of Landsat imagery provided an appropriate scale of data to study the extensive range areas of the Okavango Delta margin. However, the resolution of the individual pixels was fine enough to enable features such as fencelines and tracks to be identified, which aided data sampling and image correction procedures.

c) The availability of data for a number of separate parts of the electromagnetic spectrum (multispectral data set), increased the probability of establishing characteristic spectral responses from a variety of ground features (see chapter II). In the case of the present study, a single Landsat MSS band was used to generate the final classification used to map woody cover. However, this was the result of particular environmental circumstances. The multispectral data set was essential in establishing the form of the relationship used as the basis for classification. It also indicated that the assumption that the relationship was the result of changes in the relative amounts of woody vegetation and exposed soil was correct.

In view of the problems inherent in the analysis and classification of natural terrain, the use of Landsat data appears to offer a relatively accurate and economic method. It negates the need for extensive ground survey in difficult conditions, although some supplementary data is essential. Because of the importance of woody vegetation in the ecology and management of semi arid rangeland (and other landuse types, such as national parks and reserves (Heady and Heady, 1982)) throughout Africa, the technique described in this chapter could provide useful information for effective, sustained exploitation of range resources. The method provides a realistic alternative to the use of other methods (for example the use of aerial photographs to evaluate bush encroachment (Williamson and Keech, 1983)).

VI. The Role of Physiognomy in the Reflectance Characteristics of Areas of Woody vegetation.

6.1 Introduction.

It was shown in Chapter V, that it is possible to use Landsat imagery as a means of assessing the distribution of woody cover within the Kalahari Sandveld terrain type. The results (1983 Landsat data) have also suggested that differences in species composition did not cause any significant variation in the reflectance characteristics of the vegetation in that environment (and date of imagery). There was also some indication that this may have applied to differences in the growth form of the vegetation (trees or shrubs).

Because all the vegetation types present within the Kalahari Sandveld study area consisted of low tree and shrub savanna, with both elements present in varying amounts, it was not possible to fully assess the significance of any physiognomic differences. This did not apply to the Mopane Sandveld areas, in which the dominant woody species (*Colophospermum mopane*) showed a tendency to form a mosaic of well defined patches of open woodland and shrub (or scrub) savanna. The Mopane Sandveld environment is similar to that of the Kalahari Sandveld in many respects (see sections 4.8.2(e) and (f)). Differences occur mainly in the species composition of woody vegetation and in the tendency for *C. mopane* to form distinct areas of woodland and shrub. *C.*

mopane also tends to be found in nearly pure stands, with associated species forming a very minor part of the total vegetation. This provided an opportunity to test the role of physiognomy in affecting reflectance characteristics.

The two physiognomic types (woodland and shrub) of C. mopane vegetation are often associated with differences in topography; the shrub savanna is usually encountered in low lying areas, such as the depressions between sand ridges, while the higher ground is usually occupied by woodland. This was particularly noticeable in the Mopane Sandveld areas to the south and west of Maun, which displayed the ridge and swale topography associated with old linear dune features. Various explanations have been offered as to the formation and maintenance of the separate physiognomic types, these are briefly mentioned in section 4.8.2 and are discussed more fully below.

It was noted (section 4.8.2(e)) that the C. mopane shrub and woodland areas produced distinct, contrasting spectral response patterns on a number of the Landsat images investigated during the terrain analysis. Because C. mopane usually forms near pure stands, it is unlikely that differences in species composition accounted for these differing reflectance characteristics. An investigation of the factors affecting the reflectance characteristics of C. mopane, would also indicate whether the type of relationship established for the Kalahari Sandveld, between reflectance data and percentage woody cover, could be adapted for use in Mopane Sandveld areas.

An analysis of the multitemporal Landsat data, of an area of C. mopane woodland and shrub mosaic, could also provide information on the factor or factors involved in the formation and maintenance of the two separate physiognomic types.

6.2 Formation of the Colophospermum mopane woodland and shrub mosaic.

The C. mopane dominated sandveld areas of the Okavango Delta margins are regarded by Field (1978) as 'outliers' of the main distribution in north eastern Botswana. As a species, C. mopane appears to be extending it's range within southern Africa, at the expense of other savanna forming species (Cole, 1982a). This Okavango 'outlier' of C. mopane dominated savanna probably represents the south-ward invasion front of the species into the mixed species low tree and shrub savanna of the Kalahari region. Cole (1982a) regards the Okavango region as a vegetation tension zone, the boundary between various vegetation types, such as the two noted above, being held in tension by the prevailing enviromnental conditions. Changes in the conditions may cause a shift in the spatial pattern of the main vegetation types. The major factor in creating a tension zone in the Okavango region is the juxtaposition of the delta wetlands and the semi-arid Kalahari. The factor (or factors) controlling the boundary between the C. mopane dominated savanna and the mixed species low tree and shrub savanna are not clear (Astle, pers. comm.).

Various suggestions have been made regarding the formation of the mosaic of woodland and shrub. Prince (pers. comm.) suggests that the height of the plants is related to the depth of an impervious layer in the soil; the deeper the free-draining material above the impervious layer, the taller the vegetation, citing the example of the Luangua valley (Zambia). However, he is not certain that this applies to Botswana. Ellis (1950), also cited by Thompson (1960), accepts the idea of an association between C. mopane growth and impeded drainage or shallow water penetration. Alternative explanations suggest factors which affect those parts of the plant which are above ground. Tinley (1966), based on observations in the Moremi area, attributes the formation of the 'stunted' shrub areas to the affects of fire (pryrophytic shrub savanna). He notes that where the "...tree growth is changed to shrub or scrub growth; typically, multiple-stemmed coppices are produced from the base of a charred original stem." He suggests that changes in the growth form may lead to more extremely hot fires and a perpetuation of the shrub areas. The coppice form was found in the present study area (see section 6.3.2b). Cole (1982a) notes that individual plants are markedly shorter along drainage lines where cold air accumulates during winter nights. She believes that frost damage is the main factor in producing and maintaining a stunted growth form. Tinley (1966) notes that frost action may have a role in maintaining the shrub form once it has been produced by fire. Keet (1950) notes that C. mopane "...suckers and coppice shoots are more sensitive to the effect of frost, drought and fire than seedlings of the same age or size ..." Excessive browsing and other forms of mechanical damage by by animals may also inhibit the growth of the shrubs (C. mopane is regarded as a good browse species (Hendzel, 1981) and is likely to be used by cattle during times of general environmental stress, such as a drought, thereby further stressing the plant). In the absence of fire, climatic or biotic factors, the shrub form would be expected to mature into woodland (with multiple-stems if the shrub was of a coppice form).

6.3 Ground survey site, Moshu area (1983).

6.3.1 Introduction.

The area chosen for ground survey and comparison with the Landsat data was an area of characteristic C. mopane woodland and shrub savanna about twenty five kilometres south-east of Maun. The site occurred close to the Government agricultural research station at Moshu. Figure 6.1 shows the location of the site and the distribution of the shrub and woodland vegetation types. The map was based on 1:40 000 (black and white) aerial photographs (1973), with the aid of ground observations and aerial photography obtained in 1983. The boundaries between the vegetation types were clearly visible at ground level at the time of the field survey (fig. 6.2).

The area was traversed by several cut lines, which allowed access for ground data collection and were used as transect lines to check the distribution of the vegetation types against the aerial photographic data (fig. 6.1). The detailed ground investigation sites were located along the

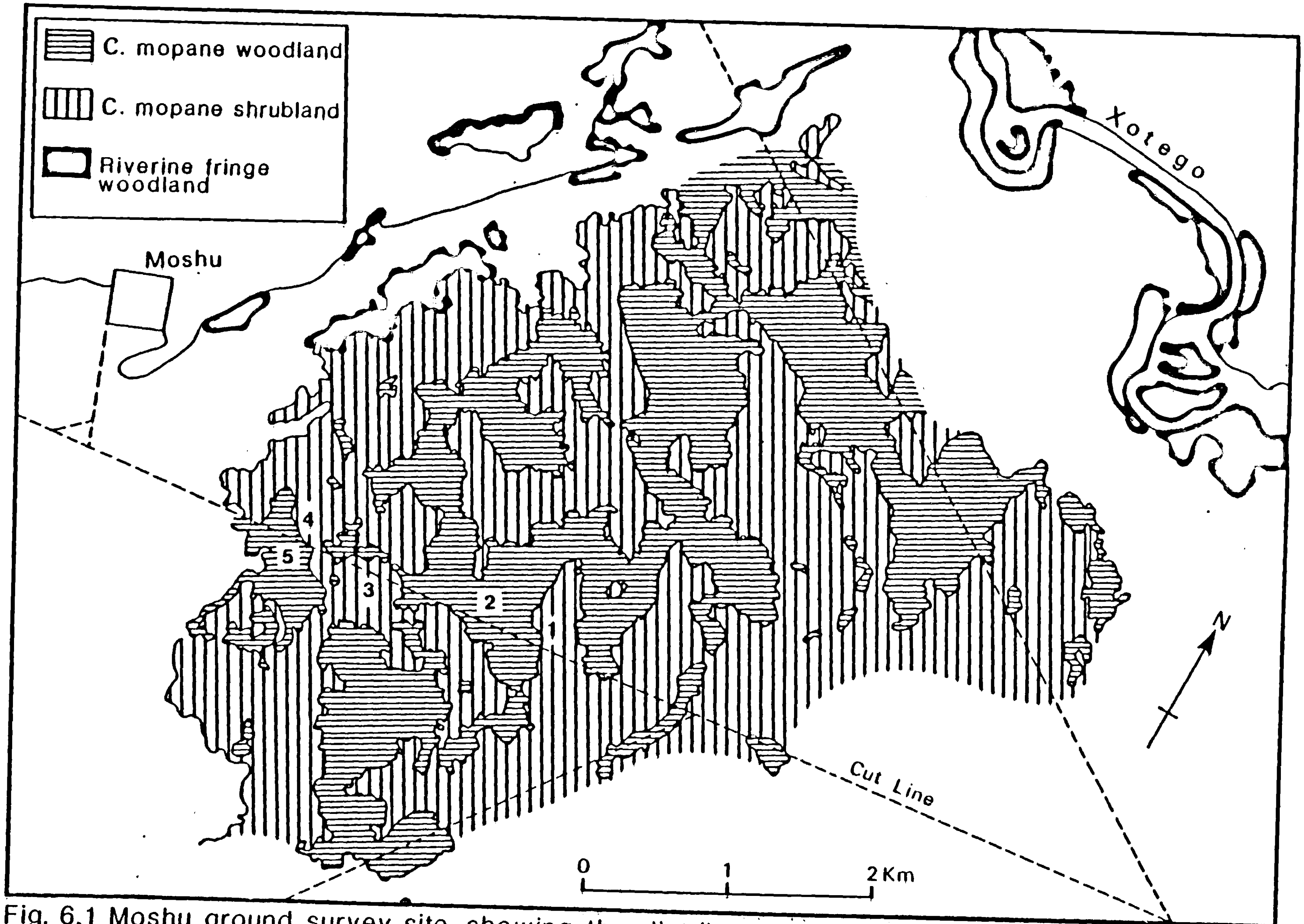


Fig. 6.1 Moshu ground survey site, showing the distribution of Colophospermum mopane woodland and shrub savanna.

Fig. 6.2 Colophospermum mopane woodland-shrub savanna boundary.

cutline leading to the Moshu Research Station. Five sample areas were chosen (see fig. 6.1), three within the shrub areas and two in the woodland areas.

The terrain at Moshu was typical of the ridge and swale topography associated with old dune features.

6.3.2 Ground survey.

A detailed discussion of ground sampling design for use in remote sensing surveys is given in sections 5.5 and 5.6. The ground survey at Moshu involved setting up twelve, 30 m x 10 m quadrats in each of the two vegetation types. Because of limitations of access and problems of locational accuracy, the quadrats were located systematically, parallel to the main cutline. This form of sample location meant that quadrats were located both near to the boundary between the vegetation types and at some distance. The quadrats were set up at least 10 metres from the cutline to avoid any influence of the cutline on the vegetation. It was noticed that in the shrub areas, those shrubs within the first one or two metres of the cutline were considerably taller than those of the general canopy. A number of factors might account for this phenomenon, for example the lack of competition for moisture and nutrients from the non-vegetated area. Detailed information was collected for each quadrat on various soil and vegetation parameters. Soil colour (Munsell) and texture were noted, and estimates of the amount of bare soil and litter cover made (the same methods were employed as those used at the Tsetseku site). The average canopy height was estimated for all quadrats and a brief description of the state of both the woody and ground layer vegetation were made. The total number of woody plants rooted within each quadrat, together with sub-totals for each individual species present, were noted (table 6.1).

Cover and profile diagrams were plotted for four quadrats in each of the vegetation types.

a) Colophospermum mopane woodland.

C. mopane woodland was invariably associated with the higher ground within the Moshu survey area. This was confirmed by analysis of stereo pairs of the 1:50 000 (1983) aerial photography of the site. The canopy layer was between 6 to 8 metres in height (fig. 6.3a), with occasional emergents (C.mopane has been noted reaching heights of up to 23 metres along the Kwaii River floodplain, Moremi (Tinley 1966)). The crowns tend to be narrow in younger trees, and appear to broaden with age. The crown diameter of the canopy forming, mature trees was generally about four metres. A number of smaller C. mopane trees (about 3 metres high) were often found beneath the canopy, together with a low shrub layer of mixed species. The quadrat data indicated that the total number of woody plants per hectare was over six hundred and eighty. Of this total, 44% were C. mopane trees and 19% C. mopane shrubs. The shrub layer was dominated by two species, Grewia flavescens and Ximenia americana ('Sour plum'). X. americana tended to form small, dense, spiny thickets around the base of C. mopane trees. G. flavescens was evenly scattered beneath

Table 6.1 Summary of Vegetation Survey Results, Moshu 1983.

	Total No.	Density	Plants/ha
a) *C. mopane* shrub			
A. anthelmintica	3	0.3	10
A. erioloba	1	0.1	3
A. erubescens	3	0.3	10
A. tortillis	5	0.4	13
C. mopane	678	56.5	1883
D. cinerea	20	1.7	57
G. flavescens	47	3.9	33
P. leubnitzii	2	0.2	7
Unidentified	10	0.8	27
TOTAL	769	64.1	2136
b) *C. mopane* wood			
A. erubescens	1	0.1	3
C. mopane	155	12.9	430
(tree sub-total)	(109)	(9.1)	(303)
(shrub sub-total)	(46)	(3.8)	(127)
D. cinerea	3	0.3	10
G. flavescens	32	2.6	87
L. nelsii	15	1.3	43
R. tenuinerus	2	0.2	7
X. americana	31	2.6	87
Unidentified	8	0.6	20
TOTAL	247	20.6	687

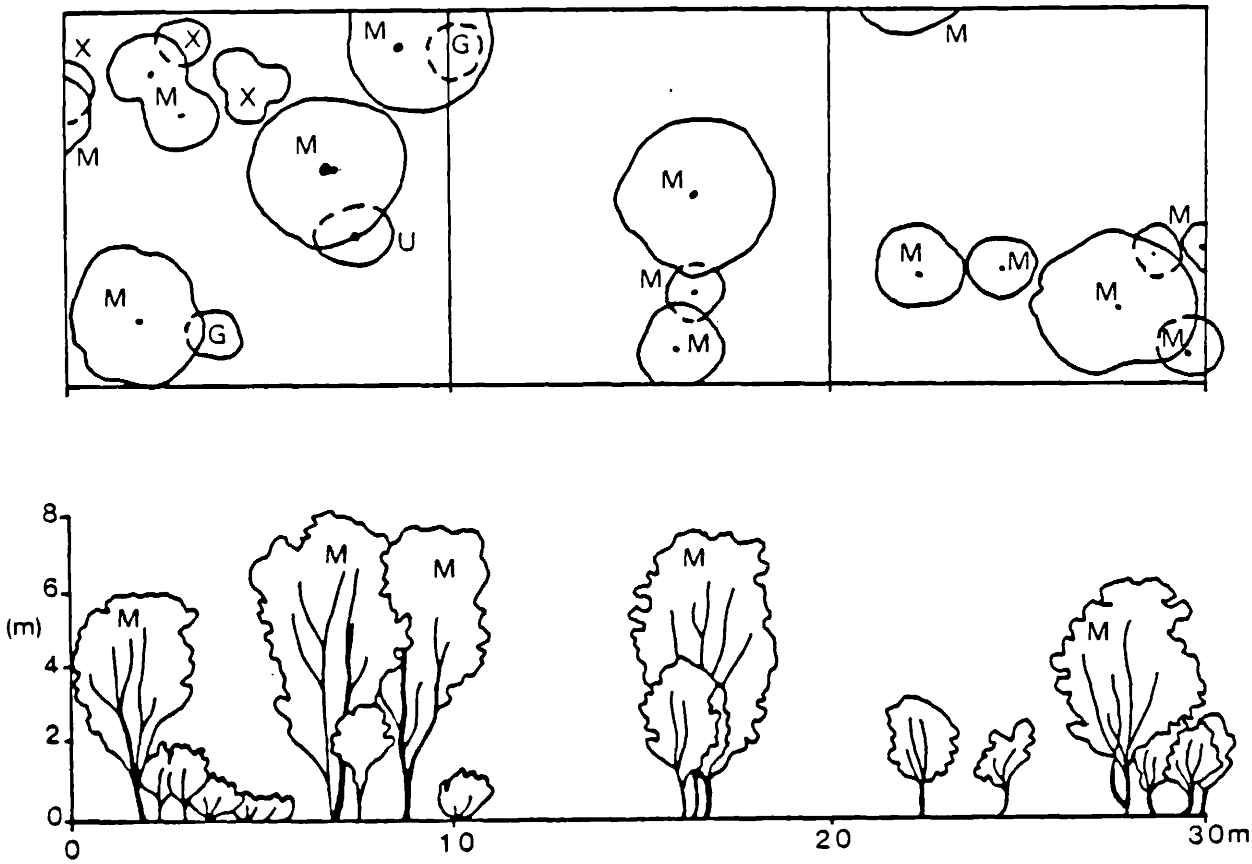


Fig. 6.3a Profile and cover diagram of Colophospermum mopane woodland.

G - Grewia sp.
M - Colophospermum mopane
X - Ximinia americana
U - Unidentified

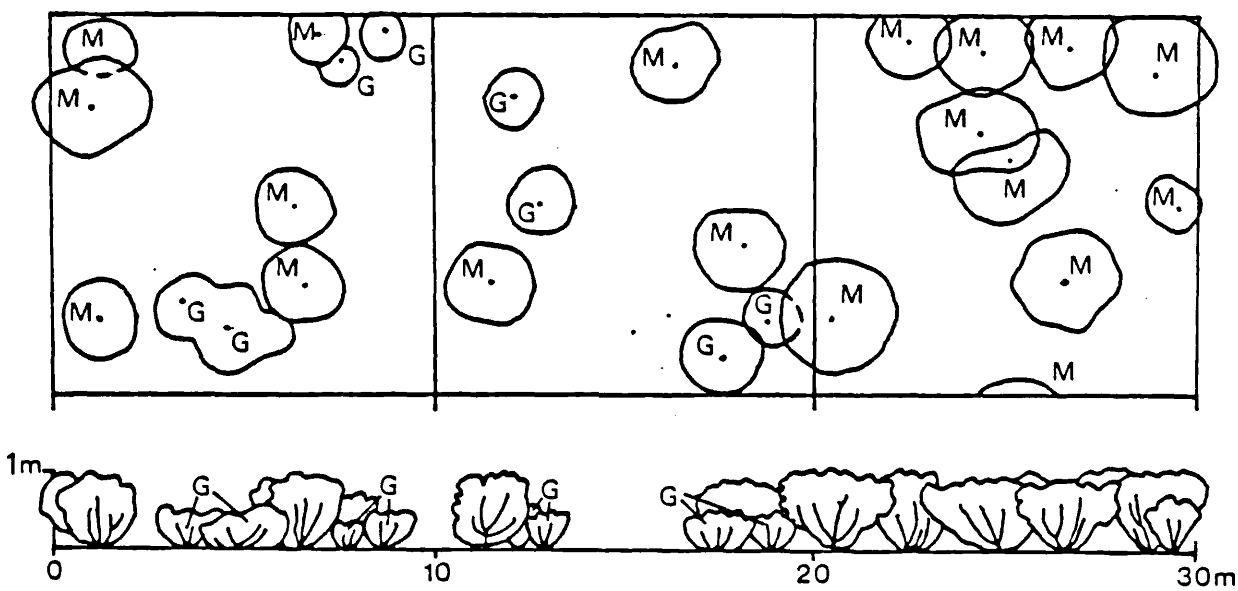


Fig. 6.3b Profile and cover diagram of Colophospermum mopane shrubland.

the canopy. These two species each accounted for 13% of a woody plants recorded.

At the time of ground data collection (and imaging by Landsat) the tree canopy still retained healthy green leaves, a few trees had begun to turn the characteristic yellow (later reddy brown) of C. mopane vegetation during the dry season. This was in contrast to the shrub areas, where many of the plants had begun to change colour (fig. 6.2).

The cover diagram and profile in figure 6.3a provide an indication of the structure of the woodland at Moshu. The values for percentage woody cover varied from 24.6% to 37.8% for the four cover diagrams plotted (mean value 32.3%).

The ground layer vegetation was generally in poor condition, grasses were predominant. Grass cover in the woodland areas tended to be medium to low, with high amounts of bare ground. Mopane leaves provided the main source of surface litter, although the overall amount of litter cover was low. The leaves of C. mopane did not appear to be readily incorporated into the soil; much of the litter was composed of entire, dead leaves from the previous winter. The presence of dry litter increases the risk of fire, however, the Moshu site showed no signs of recent burning in either the woodland or shrub areas.

Fine sandy soils were recorded throughout the woodland areas. These were grey (10YR 5/1) to greyish brown (10YR 5/2) in colour. The surface was structureless, loose sand, often disturbed by trampling (cattle). Staring (1978) associates the distinctive C. mopane woodland with "...deep, somewhat excessively drained, (loamy) fine sands..." ('Shorobe series'). He notes that semi-hard calcrete is usually encountered within 150 cm.

b) Colophospermum mopane shrub savanna.

The C. mopane shrub savanna (Tswana name, 'Mopanyane' or 'small Mopane') was found within swales between the ridges of higher ground. A very distinct boundary existed between the shrub savanna and the woodland areas. Within individual areas of the shrub savanna (separated by areas of woodland), the majority of the individual plants are of a very similar height and diameter, forming a very uniform canopy (fig. 6.3b). The values measured for woody cover, from the cover diagrams, varied between 28.0% and 32.3% (mean value 29.8%). The height of shrubs varied between 1 m (areas 1 and 4) and 1.5 to 2 m (area 3). The shrubs were characteristically coppice-like in structure, multiple stems growing from a central base at soil level. The quadrat data indicated that the total number of shrubs per hectare was over two thousand and forty. C. mopane shrubs accounted for 92% of all recorded plants.

Very few trees are found in the shrub areas, those that were, were restricted to patches near the edge of the woodland or were found on ground raised above the general level of the depression (for example, old termite mounds).

The ground layer was dominated by grasses, with medium to low amounts of cover. Exposed soil area was high, with only low litter cover (mainly leaves of C. mopane).

Other species of shrubs form a very small component of the vegetation, both in terms of number and cover. Grewia flavescens is found most frequently, with only scattered examples of Acacia and other shrubs. X. americana appeared to be totally absent, being associated exclusively with the woodland. Dichostachys cinerea was recorded in only one quadrat.

The soils encountered in the shrub areas were fine sands (similar to those of the woodland areas). They varied in colour from grey (10YR 5/1) to light grey (10YR 7/1). Staring (1978) associated C. mopane shrubland areas with deep, well drained, (loamy) fine sands ('Moremi series'). However, unlike the 'Shorobe series' associated with the woodland areas, he stated that "Calcareous material is not generally encountered within 150 cm."

6.4 Analysis of the Landsat MSS data.

6.4.1 Introduction.

Multitemporal Landsat data was available for the Moshu site for the period 1972 to 1983. A number of enhancement procedures were employed to generate imagery of the Moshu area for the various dates. Visual interpretation of image content was made, specifically to assess whether the data could be used to distinguish areas of C. mopane shrub from woodland.

The visual analysis was complemented by statistical analysis of sampled digital data values.

6.4.2 Visual interpretation of multitemporal imagery.

The multitemporal imagery analysed represented varying seasonal and climatic conditions (fig 3.4). These factors are discussed in the context of observed changes in the response values (of the shrub and woodland areas) over time as seen on the imagery. Conventional (contrast stretched) colour composites were found to provide the most useful form of enhanced imagery throughout the visual analysis, therefore all references to the image characteristics refer to these unless otherwise stated.

Evidence from aerial photography (1973 and 1983) suggests that the pattern of woodland and shrub in the Moshu area has not altered substantially during the period of available Landsat imagery. The boundaries were clearly evident between the two vegetation types at both dates.

a) 15 September 1972. The boundaries between the woodland and shrub areas were not generally distinct on any form of the enhanced imagery. There was some difference in colour and tone between the areas (as seen on the colour composite image); the woodland areas appeared pale grey to brown, the shrub areas were pale grey or white. September is the very end of the dry period, this might account for a lack of spectral response characteristic of green vegetation. Aerial photographs showed that woodland occupied the same sites in March 1973 as in 1983, therefore, a standing tree cover must have been been in existence at the time of the September image. This also applied to the shrub areas.

b) 19 January 1973. The boundaries between the vegetation types were very distinct and they displayed very different spectral response characteristics (fig. 6.4). The woodland was seen as areas of medium brownish (or greyish) red, in contrast to the shrub areas, which remained pale grey or white. By January of 1973 it is probable that sufficient rain had fallen to allow the trees to produce green leaves and the spectral response characteristic of this. The aerial photography showed an established shrub cover to be present in early 1973, however, it does not seem to have responded in the same way as the woodland areas.

c) 22 August 1975. The boundaries were again very distinct. The presence of a large fire scar over the study area was evident from the imagery. The site atwhich the fire was initiated appeared to have been along the line of a track which runs parallel (approximately two kilometres south) to the Moshu cutline. The shape of the scar (and of others seen on the whole Landsat scene) indicated a south-south-easterly wind direction at the time of the fire. The scar covered the whole of the Moshu site and part of the area to the north of the Xotego channel (fig. 6.5). Fires (intentional or otherwise) are a common phenomenon throughout Botswana at the end of the dry season, despite legislation prohibiting burning (Field, 1978; APRU, 1980; Samboma, 1982), (Landsat data has been used in an attempt to monitor fires in Botswana and other parts of Africa (Wightman, 1973; Deshler, 1974; Field, 1978;

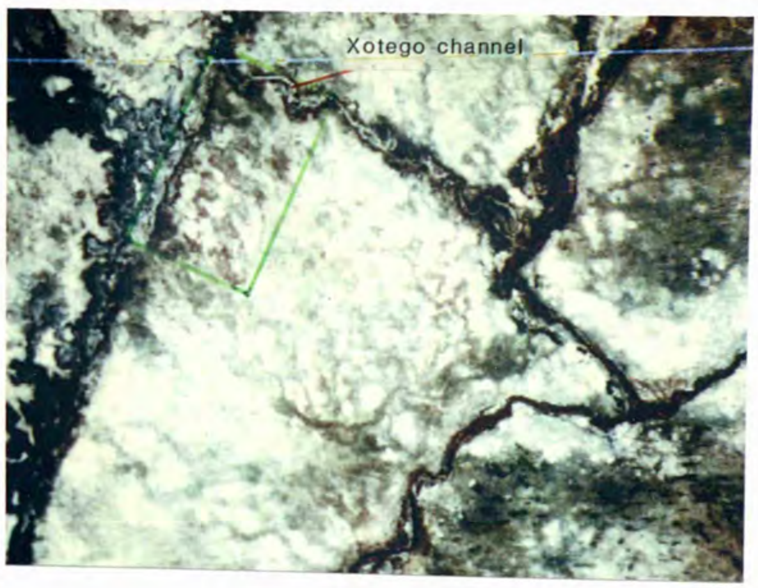


Fig. 6.4 Landsat colour composite showing the Moshu area (January 1973).

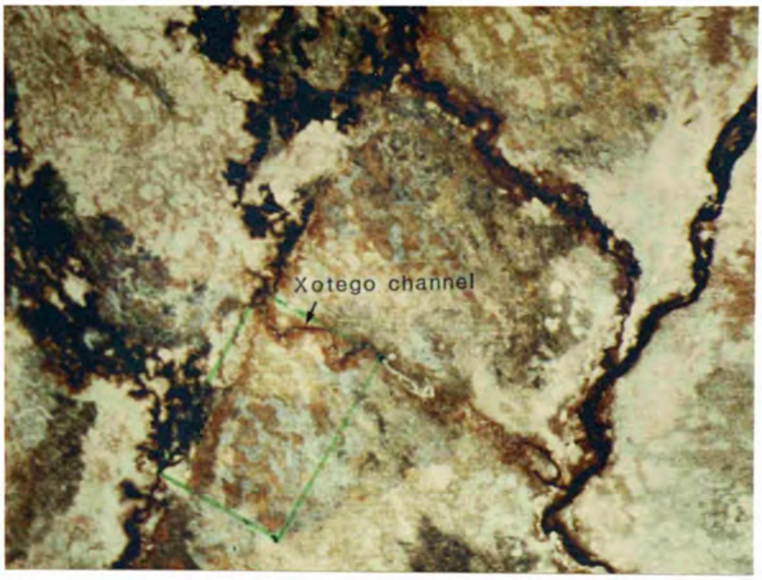


Fig. 6.5 Landsat colour composite showing the Moshu area (August 1975).

Aderhold, 1981)). Despite the fire, the woodland areas appeared as medium brownish red patches characteristic of healthy vegetation. The shrub areas were medium to pale blue grey. Burn scars are typically very dark in tone to begin with, becoming paler in tone with time. It is not possible to date the fire that caused the particular scar, but evidence from other burns, seen on consecutive images of the Okavango area, suggests that scars fade fairly rapidly. The Moshu fire was probably within the preceeding month. The scar was clearly visible on images of all the individual MSS bands on 22 August, however, eighteen days later (9 September) it could only be clearly distinguished on an image of MSS band 7 (black and white photographic products only, were obtained for this date). Cole and Owen-Jones (1977) studying the change in fire scars in the Cloncurry Plains (Australia) from Landsat imagery, noted that scarred areas appeared to return to near normal conditions in about seventeen months. The faster recovery rate in the case of the Moshu burn may have been due to the burn occurring prior to the main rains and period of most rapid grass regrowth.

d) 18 May 1976. Nine or ten months after the probable date of the Moshu fire, the scar was no longer evident on the imagery. The boundaries between the vegetation types remained distinct. The woodland again produced a medium tone reddish colour on the imagery. The shrub areas had returned to the pale grey to white of the earlier images.

e) 7 May 1983. Very little contrast between vegetation types was evident from the imagery (fig. 6.6). The boundaries were very difficult to detect despite the fact that they were clearly visible both on the ground and on aerial photographs of the same period.

6.4.3 Analysis of the digital data.

A random sample of 40 pixels within each of the C. mopane vegetation types were collected using the digital image processor (DIAD). A set of random coordinates were generated and the sample pixels located on the basis of their line and column positions. The values in each MSS band were noted for every sample pixel.

The sample data was initially plotted as bivariate scattergrams (of one MSS band against another, fig. 6.7 contrasts the scattergrams of MSS band 5 with band 7 for the 1973 and 1983 data sets). The form of the scattergrams produced, confirmed the results of the visual analysis. For those dates of imagery where the two vegetation types were seen as distinct, in terms of both spectral response and clear boundaries, the sample data formed two distinct clusters on the scattergrams. The data values for the woodland areas appeared to be consistently lower than those of the shrub areas. The scattergrams for the 1983 samples, however, showed no distinct separation of the data. A marked degree of overlap of the two groups was displayed.

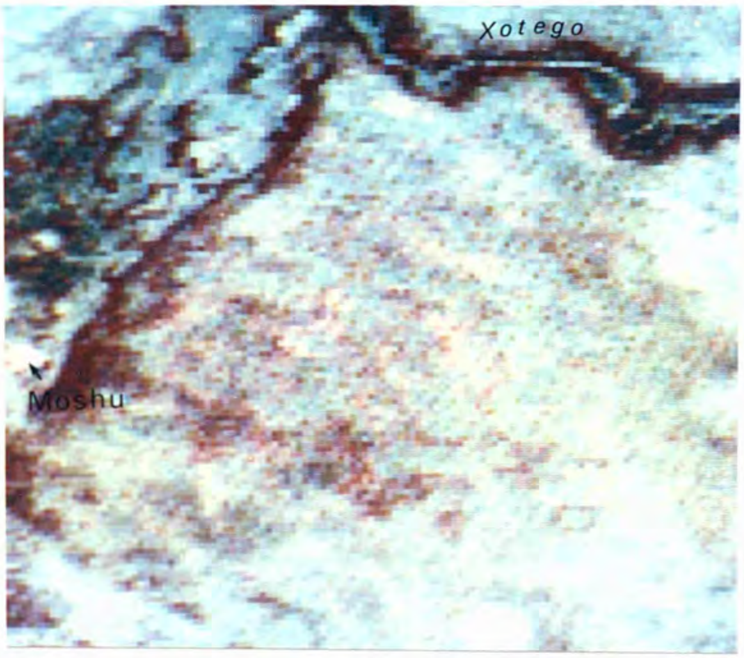


Fig. 6.6 Landsat colour composite of the Moshu site (May 1983)

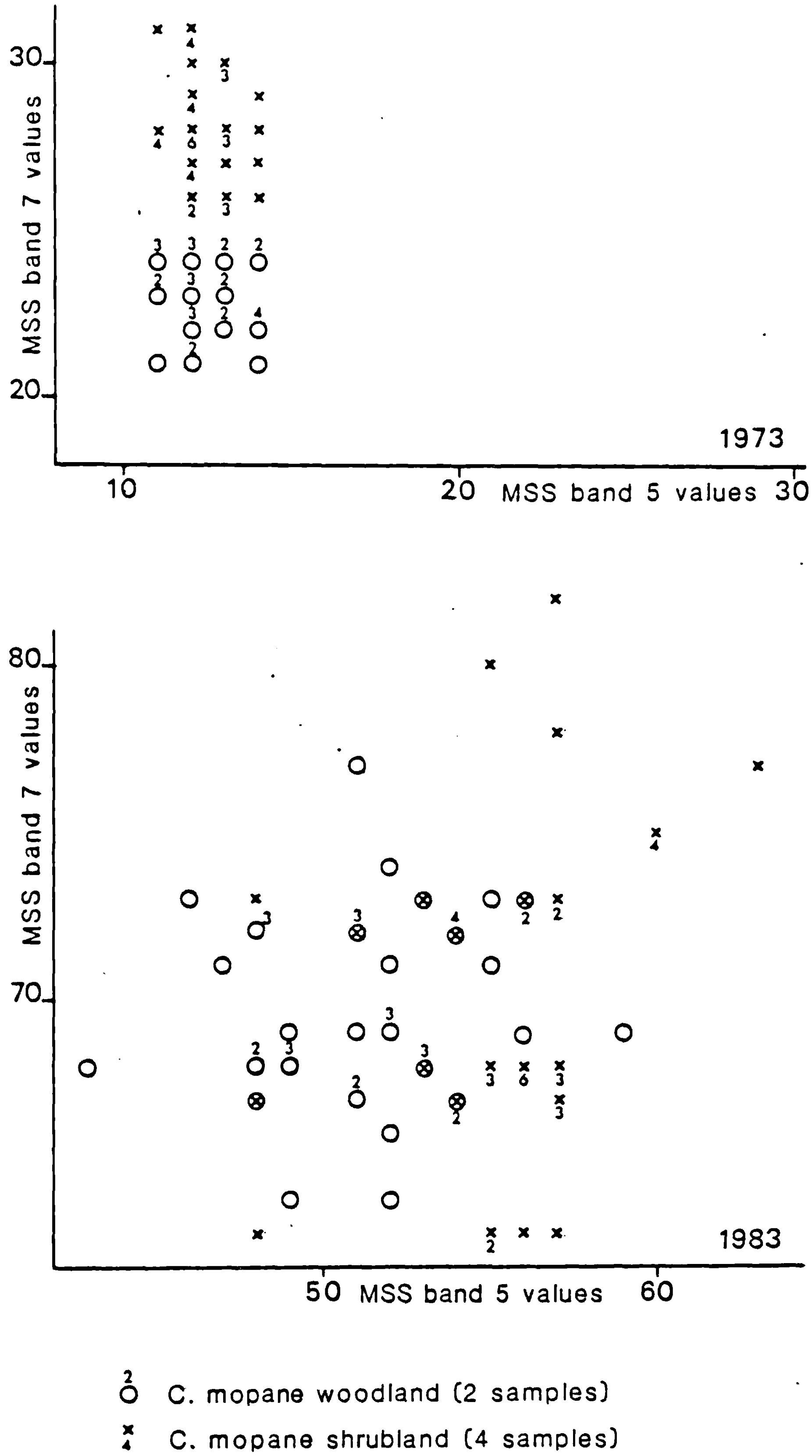


Fig. 6.7 Scatter diagrams showing the relationship between MSS band 5 and 7 values for the Moshu area for woodland and shrub savanna (1973 and 1983).

It was decided to statistically test the 1983 data for any significant difference between the two sample groups; frequency histograms of single MSS bands (showing the two groups of data) indicated that a difference in the data sets might exist in the case of certain of the MSS bands. A (two tailed) Student t test was used to test for any difference between the woodland and shrubland data sets. The data for MSS band 5 (which appeared to show some difference between the two groups of data when plotted as a frequency histogram) and band 7 (which showed a much greater overlap between the two sets of data) were tested separately. The results showed that a significant difference (at the 95% level) did exist between the two sets in the case of MSS band 5. The frequency histogram indicated that the values for the woodland data were generally lower that those for the shrub areas. This is probably the result of differences in leaf colour at this period. The shrub areas tended to be turning reddish in colour, while most of the trees remained green. Green leaves absorb red light (in the MSS band 5 range), for photosynthesis, while dying leaves do not and therefore appear yellow or red in colour. The results for MSS band 7 indicated that no significantly different existed (at the 95% level). It must, however, be noted that the Student t test is purely an analysis of means; the form of the frequency histogram for the MSS band 7 data and the calculated standard deviations indicate that while the two groups fall about a similar mean, the shrubland data tended to have a wider distribution (over the possible range of reflectance values). Much of the reflected infrared light would have been from the bare soil surface, the contribution of both types of vegetation would have been low in this case.

6.5 Discussion of results.

6.5.1 Introduction.

The results presented above must be interpreted in the light of available supplementary information. Detailed ground data for the Moshu area was only available for date of the 1983 Landsat data. Only sparse supplementary data was available for the other dates of imagery (aerial photography (1969, 1973) and climatic data).

6.5.2 Factor(s) influencing the reflectance characteristics of Colophospermum mopane vegetation types.

Analysis of the enhanced imagery and the sample data showed that differences in spectral responses between the C. mopane woodland and shrub areas did not remain constant (relative to one another) through time. A number of factors may cause variations in the responses of the two vegetation types at certain times and not at others. Differences could be caused by one or more of the following; variation in vegetation cover, leaf area, depth of canopy, leaf colour and differences in associated species.

Which of these factors controls the reflectance characteristics of the vegetation is important. It will determine whether the differences in the spectral responses at certain dates, are a product of differences in physiognomy, or of some other factor such as vegetation cover, which are not necessarily related to differences in the growth form of _C. mopane_. This will in turn determine what uses (if any) can be made of the Landsat data.

Aerial photographs for the years 1969 and 1973 show the woodland and shrub areas having the same spatial distribution as they did at the time of the 1983 ground and aerial photographic surveys. The boundaries between the vegetation types are the same as those seen on the Landsat imagery of the years 1973, 1975 and 1976. Therefore, any changes in the reflectance responses of these areas cannot be the result of changes in the distribution of woodland and shrub areas relative to one another.

A comparison of the 1973 and 1983 aerial photographs showed that changes in the amount of vegetation cover had occurred within some of the areas. The shrub areas in 1973 appeared to have a much sparser cover than in 1983, although little change appears to occurred within the woodland areas. This is consistent with the observation that numbers (and cover) of woody plants have increased in the region during the 1970's, following the drought periods of the 1960's (section 5.7.3). Established woodland areas are less likely to have suffered during the droughts than the coppice shrubs, which appear to be more susceptible to damage from extreme conditions (Keet, 1950), and therefore fluctuations in the amount of woodland cover would also be less likely.

Given that the distribution of woodland and shrub areas remained the same throughout the study period, any factors directly linked to differences in growth form, such as canopy depth, must also have been present. If these factors were a major cause of differences in recorded reflectances between the woodland and shrub areas, their influence should have been apparent throughout the whole period, unless another factor had masked them. It is possible, for example, that large differences in cover between the two vegetation types, could have masked the influence of physiognomic factors. In which case their influence should have been observable when the woodland and the shrub areas displayed comparable cover values. Cover values appear to have been similar at the Moshu site in May 1983 (see section 6.3.2). However, the Landsat data for this period displayed the least distinction, between the two vegetation types, of all the Landsat images. Analysis of the digital data also tended to confirm this. This indicates that physiognomic factors are not responsible for the differences in the reflectance characteristics of woodland and shrub seen on some of the imagery.

The ground survey also confirmed that associated species were of minor significance within both of the C. mopane vegetation types (at Moshu), therefore this factor is extremely unlikely to have had any affect on the recorded reflectance levels within either of the areas.

The results do suggest that the main factor affecting reflectance levels is the percentage cover of vegetation. This will probably include both woody and herbaceous cover in certain circumstances. The differences in spectral response between the two vegetation types, as detected on the imagery of the mid-1970's, was probably the result of low cover values in the shrub areas contrasting with higher values in the woodland areas. The shrub areas were seen as pale areas on the imagery, the result of high reflectance values in all four MSS bands due to low cover values. In contrast, the woodland areas were much darker in tone, the result of low reflectance values due to high cover values. On the basis of the relationship established between woody cover and MSS data for the Kalahari Sandveld area, this would be the expected result. By 1983, the cover values for woodland and shrub were much closer. This would account for the difficulty in distinguishing these areas on the imagery, and for the observed the overlap in the two groups of sample data. The ground survey indicated, that while similar, the woodland areas still had slightly higher overall cover values. This accounts for the fact that the MSS band 5 sample data was significantly different for the two groups; the values in the woodland sample being generally lower than those of the shrub area.

The results indicate that the main factor influencing the reflectance responses of both the Mopane Sandveld and the Kalahari Sandveld areas is therefore the same; the amount of vegetation cover (relative to exposed soil area). As the soils of both areas are very similar (and other factors, such as amount of surface litter, are also comparable), it can be assumed that the form of the relationship will be similar for both terrain types. It is, therefore, highly probable that Landsat data could be used to map the distribution of woody cover in the Mopane Sandveld in a similar manner to the classification developed for the Kalahari Sandveld. The data could not, however, be used to distinguish physiognomic differences with any certainty as there appears to be no relationship between the amount of woody cover and the growth form of C. mopane. Photographic and ground survey evidence (from throughout the Mopane Sandveld areas) showed that cover values, for both the woodland and shrub forms, varied not only in time, but also spatially.

6.5.3 Use of Landsat data in understanding the factors influencing the growth form of Colophospermum mopane.

Analysis of the multitemporal Landsat data does provide information on possible factors involved in the maintenance of the pattern of C. mopane woodland and shrub at Moshu. However, the data does not allow direct observation of the formation of the vegetation patterns, as they were already established in the Moshu area by 1969.

The evidence from the Landsat data suggests that fire is one of the factors with a role in maintaining the shrub growth form. The effects of a fire in 1975, were seen on Landsat imagery for August and September of that year. The extent of the fire scar, visible on the imagery for August, shows the whole of the Moshu site and much of the surrounding area to have been affected. The imagery indicates that the woodland areas were not seriously affected by the fire. These areas continued to produce spectral responses characteristic of healthy green vegetation (seen as red areas on the colour composite). The shrub areas, however, displayed very different reflectance characteristics, typical of burnt areas prior to the recovery of vegetation. It seems the mature woodland trees were able to survive the effects of the fire better than the shrubs. Keet (1950) notes that coppice growth (as found at Moshu), performs less well under stress (including fire) than seedlings of the same size and age. Thus, the effect of the fire was to maintain the pattern of vegetation in the pre-burn form. According to Tinley (1966) the coppice form of shrub growth is indicative of fire as the formative factor. However, it may simply be that fires have imposed this growth form on shrub vegetation caused by another factor.

It also appears that drought may have a role in maintaining the shrub growth form. There is evidence that the number of woody plants increased in the sandveld areas (of the Okavango region) during the 1970's (section 5.7.3), and that this may have been recovery following the drought conditions of 1960's. This form of stress would also affect the shrubs more seriously than the established woodland trees (Keet, 1950). Changes in the reflectance characteristics of the shrub areas from the early 1970's to 1983 are consistent with an increase woody vegetation cover in the shrub areas, while the woodland areas appear to have remain relatively constant.

The pattern of vegetation with regard to topography is also consistent with the observation by Cole (1982a), that the shrub form is restricted to low lying areas which experience very low winter temperatures and occasional frost.

It is probable that all of these factors interact to interrupt the development of the shrub form into woodland.

The Landsat data provided no direct information on sub-surface conditions which may have caused the woodland and shrub mosaic. However, it is interesting to note that Staring (1978) associates the woodland areas with soils having a semi-hard calcrete layer at about about 150 cm depth, while no such layer is associated with the shrub areas. This is counter to an explanation offered by Prince (pers. com.), in which _C. mopane_ tree growth in the Luangua Valley (Zambia) was "...related to the depth of an impervious layer in the soil; the deeper the free-draining material above this the taller the trees." Cole (1960, 1982a) has also suggested that a near-surface, impervious layer could restrict or exclude tree growth (by causing water logging of the soil during the wet season) in savanna areas. The explanation, with regard to the situation described by Staring (1978), may be that the semi-hard calcrete actually improved soil moisture conditions in this instance. Staring notes that the fine sandy soils of the _C. mopane_ areas are often excessively drained. Thus calcrete may help to retain rain water and make it available for the development of a woodland cover. This could also account for the relative success of the woodland areas in times of low rainfall. The work of Cole and Le Roex (1978) in Botswana and South West Africa (Namibia), also indicates that calcrete would not form a barrier to nutrient circulation. A detailed soil survey would be required to see if this explanation is responsible for the actual pattern of vegetation observed at Moshu.

Analysis of the multitemporal Landsat data shows it has a valuable role as a source of historical information; providing a tool for the study of the development of vegetation patterns in time and space. It can be used to monitor phenomenon such as fire (or flooding, see section 4.8.2(a)), which may affect vegetation patterns and which are 'visible' to the sensor system. However, the results again highlight the need for adequate supplementary data (especially ground data), to aid the interpretation of the Landsat data.

VII. Conclusions and recommendations

The research has investigated the potential of Landsat MSS data to develop a method of terrain analysis which is suitable for the type of environmental conditions encountered within the Okavango region; a generally flat and featureless landscape. The method has been compared with other approaches to terrain analysis; usually employing conventional (stereoscopic) aerial photography.

Preliminary investigation of the MSS and aerial photographic data showed that a classification based on physiographic parameters, particularly relief and drainage (used in the 'land systems' approach (Christian and Stewart, 1953), and developments of this (MEXE, 1965; Ministry of Overseas Development, 1970)), would not be appropriate for an analysis of terrain of the Okavango region. Instead, the use of vegetation parameters, identified by the characteristic reflectance response curves, were recognised as potential indices of terrain types during the preliminary analysis of the remotely sensed data. The value of vegetation as an index had been noted by Cole (1982b), who emphasized that it reflected "... the interplay of current climatic and edaphic conditions, and the legacy of past climatic and geological events." Vegetation may also be indicative of current and former land use practices.

The results of the terrain analysis and classification using the Landsat MSS data (together with additional data from aerial photography and ground data) have shown that vegetation does provide a useful basis for evaluation of terrain in the Okavango region. Reflectance responses from vegetation generally dominated over that from other terrain components on the sub-scenes of the Landsat imagery that were analysed. The main exceptions to the dominance of vegetation responses, were from large pans, water bodies and zones of human settlement.

The MSS data also provided information on drainage conditions, edaphic and geological features, which could not be obtained from conventional aerial photography.

Sequential Landsat imagery provided data for evaluation of the role of seasonality and climatic fluctuations on the reflectance responses of the terrain. Specific changes in response were shown to correspond to particular changes in ground conditions; for example, variation in the extent of flooding of 'molapo' floodplain areas, caused by fluctuations in annual precipitation over the Okavango Delta's catchment, could be monitored.

The terrain classification provided a framework from which it was possible to identify specific sites (on the basis of characteristic reflectances) for detailed investigation of particular rangeland resource problems. The classification was also used to establish limits for the extrapolation of results based on detailed study within a particular terrain type.

The study showed that a classification based primarily on visual analysis and interpretation of enhanced imagery provided the best results. Computer based classification procedures did not provide the versatility required to distinguish between many of the ground components. Computer based methods differentiate between areas purely on the basis of reflectance values, and unlike visual analysis, could not take into account other factors such as texture, shape and size of features visible on the imagery. This finding was consistent with the results obtained by Cole and Owen-Jones (1977) for areas of complex natural terrain in Queensland, Australia.

The terrain classification was employed to select areas of specific reflectance characteristics for the investigation of particular problems associated with the utilisation of natural terrain for livestock production. The role of woody plants as a component of rangeland vegetation was examined; the value of woody vegetation for browse and shade, and the problem of 'bush encroachment' were evaluated. Ground survey (at Tsetseku Ranch) indicated the importance (in terms of numbers) of good browse species as a component of Kalahari sandveld vegetation. Woody cover did not appear to have a direct affect on the amount of grass cover as suggested by Van Rensburg (1971b) and APRU (1975) working in Botswana, although woody vegetation, especially thorny species, did appear to restrict the access of livestock to grazing.

Relationships between reflectance values and woody cover were established, which enabled the Landsat MSS data to be used for mapping spatial variation in woody cover (other relationships which might affect the reflectance characteristics of woody vegetation were also examined; for example, physiognomic differences). The strongest relationship a highly significant negative correlation was found between woody cover and MSS band 5 values (visible red light). The negative correlation appeared to result from a combination of factors related to the spectral response characteristics of green vegetation and of the very dry, light coloured soils encountered in the Kalahari sandveld areas. The relationship is dependent on a specific set of environmental circumstances; for example, the spectral response curves of the soils would be affected by changes in surface moisture conditions.

Other variables examined, such as differences in species composition andphysiognomy of woody vegetation, did not appear to affect significantly the reflectance characteristics of the sandveld terrain within the study area. The investigation of contrasting areas of Colophospermum mopane woodland and shrubland, indicated that the ratio of woody cover to exposed soil was more important than differences in growth form, even where this difference is very marked.

The relationship between the MSS band 5 values and woody cover provided the basis for a classification and mapping procedure. A linear regression calculated from the woody cover and MSS band 5 data, was used to predict class ranges. Classified images were generated by density slicing of the MSS data. The levels of classification accuracy obtained, were regarded as acceptable given the nature of the terrain and the difficulties inherent in other methods of mapping cover in an area of poor accessibility. The results indicated that the use of multispectral data can provide an additional dimension to the methods currently employed in this type of survey (aerial photography and ground survey). The digital format greatly increased the rapidity with which large areas of terrain could be accurately classified and mapped.

The fact that it was possible to identify such a strong relationship between a particular ground phenomenon and reflectance values, was aided by the availability of contemporaneous Landsat, aerial photographic and ground data, The problems inherent in surveys which do not have temporally contiguous data were thus eliminated. Once a relationship has been established using contemporaneous data, it may well be possible to apply the results to imagery of differing dates for which ground data is not available. There are clearly practical limitations to the acquisition of contemporary data from different sources. Landsat data can still provide a valuable source of information, especially when no other data is available as is the case for many regions in the developing world.

The results of the study demonstrate the potential value of the Landsat MSS data for a specific rangeland evaluation task. The type of relationships identified, may well provide the basis for the solution of other problems of concern in developing countries. These include various environmental monitoring and resource management problems. The relationship between the ratio of woody cover to exposed soil, for example, might be applied to monitoring fuel wood resources, the subject of much concern in parts of Africa.

Imagery from the Landsat MSS system and Thematic mapper and from the new generations of multispectral earth resource satellites, for example, the French SPOT system (due to be launched in October 1985), will provide vital information for sensible, sustained use, management and conservation of resources in developing countries.

Appendix A

Ground reference data: Tsetseku.

Ground reference data was gathered during the period April to June, 1983, as part of a study to evaluate the use of Landsat MSS data for terrain analysis and rangeland management. The Tsetseku site included the Kalahari Sandveld and Riverine Zone terrain types.

A number of vegetation types were identified at the site (see section) within the Kalahari Sandveld terrain type.

a) Acacia dominated depressions.

b) Mixed species low tree and shrub savanna.

c) *Terminalia sericea* low tree and shrub savanna.

d) *T. sericea* / mixed species low tree and shrub savanna.

e) *Dichostachys cinerea* thickets.

Data collection.

Data was collected at 40 main sample sites (two 25 m x 10 m quadrats per site). A number of quadrats were set up specifically to provide cover and profile diagrams (30 m x 10 m). The position of the sites are shown in figure 4.2. The information collected at each site is given below.

a) General site description

- Topography (T)
- Erosion (E)
- Landuse (L)

b) Soil surface characteristics

- Colour (C) (Munsell class)
- Texture (T)
- Structure (S)
- Litter (L) (<10%=very low,10-20%=low,20-40%=medium, 40-60%=high,>60%=very high)
- Bare ground (B) (as for litter)
- Moisture status (M)

c) Vegetation

- General description of the site (V) (Height of tree and shrub layers, density of vegetation, etc.)
- Basal cover (BC) 5cm interval sampling on 2 x 25m line transects per quadrat.
- Total trees and shrubs per quadrat (T) and (S)
- Species composition (C) with sub-totals.

Site 1 / Inside paddock 2 at R
a) (T) level (E) some disturbance from trampling (L) ranch

b) (C) 10YR 7/1 light grey (T) sandy (S) brittle crust c.0.5 - 1cm
(L) very low (B) - (M) Dry

c) (V) Open low shrub, mixed species. c.1 - 1.5m high. Grass sparse and brown

Quadrat 1
(BC) 22 (4.4%)
(T) 0
(S) 21
(C) Croton gratissimus 4
Dichostachys cinerea 1
Acacia sieberana 1
Rhus tenuinerus 4
Grewia sp. 10
Unidentified 1

Quadrat 2
(BC) 12 (2.4%)
(T) 1
(C) Acacia arenaria 1
(S) 16
(C) Grewia sp. 7
C. gratissimus 1
R. tenuinerus 3
A. sieberana 1
A. arenaria 1
Acacia nigrescens 1
Albizia anthelmintica 1
Unidentified 1

Site 2 / Inside paddock 2 between R and P
a) (T) level (E) little disturbance (L) ranch

b) (C) 2.5Y 6/2 light brownish grey (T) sandy (S) hard/brittle crust c.0.5 - 1cm. (L) low (B) - (M) Dry

c) (V) dense trees and shrubs, T. sericea / mix. Trees c. 4-6m high, shrubs c.2-3m. Grass sparse and brown

Quadrat 1
(BC) 19 (3.8%)
(T) 7
(C) A. nigrescens 4
T. sericea 3
(S) 15
(C) Grewia sp. 9
C. gratissimus 1
A. nigrescens 1
Boscia albitrunca 1
T. sericea 3

Quadrat 2
(BC) 15 (3.0%)
(T) 6
(C) A. nigrescens 3
Grewia sp. 1
A. sieberana 1

D.cinerea 1
(S) 14
(C) Grewia sp. 11
A.erubescens 1
R.tenuinerus 1
D.cinera 1

Site 3 / Inside paddock 2 at P
a) (T) gentle slope near crest of ridge (E) little disturbance (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) brittle crust 0.5-1cm (L) low (B) - (M) Dry

c) (V) open shrubland (with scattered trees outside quadrats). Shrubs c.2m high. Some patches of green grass under protective bushes. Mixed species.
Quadrat 1
(BC) 21 (4.2%)
(T) 1
(C) Grewia sp. 1
(S) 32
(C) D.cinerea 20
Grewia sp. 3
A.erubescens 5
Combretum sp. 1
T.sericea 2
Unidentified 1
Quadrat 2
(BC) 27 (5.4%)
(T) 0
(S) 33
(C) C.gratissimus 1
A.erubescens 1
D.cinerea 25
R.tenuinerus 1
Grewia sp. 1
T.sericea 2
Unidentified 1

Site 4 / outside paddock 2 at P
a) (T) level (E) localised trampling (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) brittle crust c.0.5cm (L) low (B) high (M) Dry

c) (V) Open shrubland (scattered trees outside quadrats). Shrubs c.1.5 - 2.5m high. Mixed species. Grass sparse and brown.
Quadrat 1
(BC) 7 (1.4%)
(T) 0
(S) 16
(C) Grewia sp. 7
D.cinerea 3
Combretum sp. 1
C.gratissimus 2
R.tenuinerus 2

Unidentified 1
Quadrat 2
(BC) 14 (2.8%)
(T) 0
(S) 28
(C) _Grewia_ sp. 14
D.cinerea 2
Combretum sp. 9
R.tenuinerus 4
C.gratissimus 1

Site 5 / outside paddock 2 at Q
a) (T) level (E) localised trampling (L) common grazing

b) (C) 10YR 7/1 light grey (T) sandy (S) brittle crust, with loose sand in patches. (L) very low (B) very high (M) Dry

c) (V) Shrubs and scattered trees in a depression between ridges. Shrubs c.1.5-2.5m high. Grass sparse and brown. _Colophospermum mopane_ seedlings present in the ground layer.
Quadrat 1
(BC) 5 (1.0%)
(T) 1
(C) _Acacia fleckii_ 1
(S) 20
(C) _Grewia_ sp. 3
B.albitrunca 1
C.mopane 6
R.tenuinerus 1
A.erubescens 2
A.tortilis 3
A.mellifera 6
Quadrat 2
(BC) 4 (0.8%)
(T) 1
(C) _A.erubescens_ 1
(S) 30
(C) _A.erubescens_ 4
A.tortilis 2
C.mopane 18
Grewia sp. 1
D.cinerea 2
A.mellifera 2
Unidentified 1

Site 6 / Inside paddock 2 at Q
a) (T) level (E) No evidence of disturbance (L) ranch

b) (C) 10YR 7/1 light grey (T) sandy (S) brittle crust c. 0.5cm (L) low/medium (B) medium (M) Dry

c) (V) Open shrubland turning rapidly into dense shrubland, quadrat 1 within first zone and 2 in the second. Dense area is a zone of _T.sericea_ at the base of a ridge (_T.sericea_ becomes more dense up slope). Grass sparse and brown.
Quadrat 1
(T) 0

(S) 21
(C) _D.cinerea_ 13
A.mellifera 2
A.erubescens 1
T.sericea 5
Quadrat 2
(BC) 6 (1.2%)
(T) 0
(S) 32
(C) _D.cinerea_ 13
T.sericea 18
Unidentified 1

Site 7 / inside paddock 2 at A
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) Hard crust c.1cm (L) medium (B) medium/high (M) Dry

c) (V) Open shrubland with trees in depression. Shrubs c. 1-1.5m high and trees c. 4-5m high. Grass brown, and providing litter.
Quadrat 1
(BC) 18 (3.6%)
(T) 3
(C) _A.erubescens_ 2
A.tortilis 1
(S) 17
(C) _C.mopane_ 3
Grewia sp. 11
R.tenuinerus 1
A.tortilis 1
A.erubescens 1
Quadrat 2
(BC) 21 (4.2%)
(T) 3
(C) _A.tortilis_ 1
A.mellifera 1
Unidentified 1
(S) 14
(C) _Grewia_ sp. 8
R.tenuinerus 2
A.mellifera 1
D.cinerea 2
Unidentified 1

Site 8 /Outside paddock 2 at A
a) (T) level (E) trampling over whole area (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) hard crust c.0.5cm (L) low (B) high (M) Dry

c) (V) Open shrubland and trees with scattered dense patches. Acacia depression, shrubs c.1-2m high with trees of c.4m. Grass sparse and brown
Quadrat 1
(BC) 7 (1.4%)
(T) 2
(C) _A.tortilis_ 1

Acacia luederitzii 1
(S) 14
(C) R.tenuinerus 2
Grewia sp. 9
A.erubescens 2
A.tortillis 1
Quadrat 2
(BC) 1 (0.2%)
(T) 2
(C) A.tortil_is 2
(S) 9
(C) R.tenuinerus 2
T.sericea 1
Grewia sp. 2
A.sieberana 2
A.tortil_is 2

Site 9 / Inside paddock 2 mid-point between A and E
a) (T) level (E) localised trampling (L) ranch

b) (C) 10YR 6/2 light brownish grey (T) sandy (S) brittle and broken crust (L) medium/low (B) medium (M) Dry

c) (V) Medium to dense shrubland with scattered trees of c. 5-6m high. Mixed shrub types of c. 2.5m high.Grass brown and fairly sparse.
Quadrat 1
(BC) 20 (4.0%)
(T) 1
(C) A.tortil is
(S) 29
(C) B.albitrunca 2
Grewia sp. 9
R.tenuinerus 1
D.cinerea 7
Combretum sp. 4
C.gratissimus 4
A.erubescens 1
unidentified 1
Quadrat 2
(BC) 19 (3.8%)
(T) 0
(S) 25
(C) Grewia sp. 13
D.cinerea 6
B.albitrunca 3
C.gratissimus 1
R.tenuinerus 2

Sites 10/11/12 inside paddock 1, ′molapo′ grassland between B and C, at c.1300 paces from B. At 100,200 and 300 paces from fence line respectively.

a) (T) level (E) no disturbance noted (L) ranch

b) (C) 10YR 3/1 very dark grey, with patches of 10YR 6/1 light grey (T) sandy (with fine organic material) (S) compacted surface (L) medium (fine material). (B) low/medium (M) Dry

c) (V) Open floodplain grassland (with open parkland at edge) scattered trees and shrubs on raised mounds above level of flooding.
Grass green and low c. 3-4cm.
Site 10
Quadrat 1
(BC) 42 (8.4%)
(T) 0
(S) 0
Quadrat 2
(BC) 46 (9.2%)
(T) 0
(S) 0
Site 11
Quadrat 1
(BC) 48 (9.6%)
(T) 1
(C) A.tortilis 1
(S) 0
Quadrat 2
(BC) 44 (8.8%)
(T) 0
(S) 0
Site 12
Quadrat 1
(BC) 28 (5.6%)
(T) 4
(C) Combretum sp. 4
(S) 0
Quadrat 2
(BC) 27 (5.4%)
(T) 2
(C) A.tortilis 1
Unidentified 1
(S) 0

Site 13 / inside paddock 3 at 500 paces from E towards C
a) (T) level (E) large amount of disturbance from trampling
(L) ranch

b) (C) 10YR 8/1 white (T) sandy (S) loose sand over crust (L) very low
(B) very high (M) Dry

c) (V) Mixed species of scattered shrubs. Grass green in patches.
Shrubs c.1-3m high.
Quadrat 1
(BC) 11 (2.2%)
(T) 0
(S) 15
(C) Pluchea sp. 3
R.tenuinerus 3
Grewia sp. 6
A.tortilis 2
A.mellifera 1
C.gratissimus 1
Quadrat 2
(BC) 12 (2.4%)

(T) 0
(S) 12
(C) D.cinerea 3
Pluchea sp. 3
B.albitrunca 1
A.tortil̂is 2
A.erubescens 1
R.tenuinerus 2

Site 14 / Inside paddock 3 at 700 paces from E towards C
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 8/1 white (T) sandy (S) loose veneer of sand over crust
(L) low (B) medium/high (M) Dry

c) (V) Scattered shrubs and trees. Grass green in patches. Mixed species area.
Quadrat 1
(BC) 11 (2.2%)
(T) 0
(S) 19
(C) Pluchea sp.
B.albitrunca 1
R.tenuinerus 2
Grewia sp. 5
C.gratissimus 9
Quadrat 2
(BC) 13 (2.6%)
(T) 1
(C) A.mellifera 1
(S) 23
(C) Grewia sp. 9
Pluchea sp. 4
R.tenuinerus 2
C.gratissimus 3
B.albitrunca 3
A.tortil̂is 1
A.mellifera 1

Site 15 / outside paddock 4 at M
a) (T) level (E) Localised trampling (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) veneer of sand over brittle
Crust (L) low (B) medium/high (M) Dry

c) (V) Open shrubland with scattered trees. Shrubs c.2m high. Grass brown and dry.
Quadrat 1
(BC) 11 (2.2%)
(T) 3
(C) B.albitrunca 1
A.anthelmintica 1
Unidentified 1
(S) 15
(C) A.erubescens 2
Grewia sp. 6
R.tenuinerus 2

D.cinerea 4
Unidentified 1
Quadrat 2
(BC) 12 (2.4%)
(T) 0
(S) 14
(C) *Grewia* sp. 4
D.cinerea 6
A.mellifera 2
Unidentified 2

Site 16 / inside paddock 4 at M
a) (T) level (E) no visible signs of disturbance (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) fine veneer of sand over brittle crust c. 0.5cm. (L) low (B) medium/high (M) Dry

c) (V) Fairly open shrubland with a few tall trees (c.6-8m high). Shrubs c.1.5-2.5m high. Grass dry and brown.
Quadrat 1
(BC) 16 (3.2%)
(T) 1
(C) *A.tortillis* 1
(S) 14
(C) *D.cinerea* 5
A.erubescens 1
Grewia sp. 2
A.anthelmintica 5
Unidentified 1
Quadrat 2
(BC) 15 (3.0%)
(T) 2
(C) *A.anthelmintica* 2
(S) 13
(C) *Grewia* sp. 7
B.albitrunca 2
R.tenuinerus 1
Unidentified 3

Site 17 / Inside paddock 4 midway between M and O
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 6/1 light grey (T) sandy (S) veneer of sand over a thin crust (L) low (B) medium (M) Dry

c) (V) Scattered mixed shrubs with a few trees. Shrubs c. 1-2m high.
Quadrat 1
(BC) 20 (4.0%)
(T) 0
(S) 20
(C) *D.cinerea* 5
Grewia sp. 5
A.fleckii 2
A.erubescens 2
Unidentified 4
Quadrat 2
(BC) 19 (3.8%)

(T) 0
(S) 18
(C) D.cinerea 5
Grewia sp. 5
A.fleckii 2
A.erubescens 2
Unidentified 4

Site 19 / outside ranch at T
a) (T) level (E) localised trampling (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) thin veneer of sand over crust (L) low (B) medium (M) Dry

c) (V) Relatively dense shrubland with scattered trees. Shrubs c. 2-2.5m high. Green grass protected by thorn bushes. T.sericea/ mix.
Quadrat 1
(BC) 6 (1.2%)
(T) 0
(S) 21
(C) Grewia sp. 8
D.cinerea 3
A.erubescens 3
A.tortilis 1
R.tenuinerus 4
T.sericea 2
Quadrat 2
(BC) 5 (1.0%)
(T) 0
(S) 23
(C) A.erubescens 3
D.cinerea 2
A.mellifera 2
Grewia sp. 12
R.tenuinerus 1
T.sericea 3

Site 20 / Inside paddock 4 at K inside paddock 4
a) (T) level (E) some disturbance by trampling (L) ranch

b) (C) 10YR 6/1 (light) grey (T) sandy (S) thin veneer of sand over crust c.0.5cm. (L) low (B) high (M) Dry

c) (V) Scattered shrubs and trees. Shrubs c. 1-2.5m high. Grass green under protective cover of thorn bushes. Pluchea sp. present, but small.
Quadrat 1
(BC) 16 (3.2%)
(T) 0
(S) 14
(C) B.albitrunca 1
A.arenaria 6
Grewia 1
D.cinerea 4
A.mellifera 1

Unidentified 1
Quadrat 2
(BC) 15
(T) 0
(S) 13
(C) Grewia sp. 4
R.tenuinerus 1
B.albitrunca 1
Pluchea sp. 1
D.cinerea 1
A.arenaria 4
C.mopane 1

Site 21 / Inside paddock 4 at F
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 7/1 light grey (T) sandy (S) thin veneer of sand over thin crust (L) low (B) very high (M) Dry

c) (V) Low sparse shrubs and scattered trees. Shrubs c.1.5-2m high. Grass brown and dry, green sparse under thorn bushes.
Quadrat 1
(BC) 8 (1.6%)
(T) 0
(S) 25
(C) Grewia sp. 7
D.cinerea 6
R.tenuinerus 3
B.albitrunca 3
A.erubescens 5
Unidentified 1
Quadrat 2
(BC) 16 (3.2%)
(T) 0
(S) 14
(C) Grewia sp. 5
A.tortilis 4
R.tenuinerus 3
B.albitrunca 2

Site 22 / inside paddock 3 at the mid-point between E and F
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) loose sand (L) low (B) medium/high (M) Dry

c) (V) Open shrubland with trees. Trees c. 7-8m high, shrubs 2-3m. Grass cover patchy but green. T.sericea area.
Quadrat 1
(BC) 3 (0.6%)
(T) 1
(C) A.arenaria 1
(S) 15
(C) Grewia sp. 4
T.sericea 5
Combretum sp. 1
B.albitrunca 2

D.cinerea 1
Acacia ataxacantha 2
Quadrat 2
(BC) 10 (2.0%)
(T) 4
(C) *T.sericea* 2
A.arenaria 1
B.albitrunca 1
(S) 15
(C) *Grewia* sp. 6
A.ataxacantha 4
Combretum sp. 1
B.albitrunca 1
T.sericea 3

Site 23 / Inside paddock 4 between S and O, at corner of 51 and 17ha stocking trial areas.
a) (T) level (E) trampling (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) hard crust (L) low (B) medium (M) Dry

c) (V) Low shrubs with scattered trees. Shrubs c.2m high. Patchy green grass.
Quadrat 1
(BC) 10 (2.0%)
(T) 1
(C) *A.erubescens* 1
(S) 21
(C) *D.cinerea* 1
R.tenuinerus 1
Grewia sp. 19
Quadrat 2
(BC) 12 (2.4%)
(T) 1
(C) *A.anthelmintica*
(S) 15
(C) *Grewia* sp. 6
D.cinerea 3
T.sericea 3
Combretum sp. 3

Site 24 / Inside paddock 4 between O and S, at corner of 34 and 51ha stocking trial areas.
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) veneer of loose sand over crust c.0.5cm. (L) low (B) medium (M) Dry

c) (V) Dense shrub with scattered trees. Shrubs c.2m high. Grass green in patches.
Quadrat
(BC) 9 (1.8%)
(T) 0
(S) 26
(C) *Grewia* sp. 12
T.sericea 1

D.cinerea 12
R.tenuinerus 1
Quadrat 2
(BC) 9 (1.8%)
(T) 1
(C) T.sericea 1
(S) 20
(C) Grewia sp. 11
A.arenaria 2
T.sericea 2
A.erubescens 1
D.cinerea 2
R.tenuinerus 1
Combretum sp. 1

Site 25 / Outside ranch at 800 paces along cutline to Maun from N
a) (T) level (E) heavy trampling (L) common grazing

b) (C) 10YR 6/2 light brownish grey (T) sandy (S) loose sand (L) medium /high (B) low (M) Dry

c) (V) Open shrubland with scattered trees. Shrubs c.1.5m high. Grass brown and dry
Quadrat 1
(BC) 10 (2.0%)
(T) 0
(S) 25
(C) A.erubescens 3
D.cinerea 8
B.albitrunca 1
A.anthelmintica 1
Grewia sp. 11
R.tenuinerus 1
Quadrat 2
(T) 2
(C) A.anthelmintica 1
B.albitrunca 1
(S) 20
(C) Grewia sp. 8
D.cinerea 12

Site 26 / Outside 'bull camp' at N
a) (T) level (E) localized trampling (L) common grazing

b) (C) 10YR 7/3 (T) sandy (S) loose sand over very thin crust (L) medium/high (B) low (M) Dry

c) (V) Scattered shrubs and trees. Trees c.5-7m high, shrubs c.1.5-2m high. Grass dry and brown.
Quadrat 1
(BC) 6 (1.2%)
(T) 4
(C) Lonchocarpus nelsii 4
(S) 11
(C) T.sericea 2
Grewia sp. 4
D.cinerea 5

Quadrat 2
(BC) 7 (1.4%)
(T) 1
(C) *B.albitrunca* 1
(S) 14
(C) *Grewia* sp. 6
A.erubescens 1
D.cinerea 3
T.sericea 4

Site 27 / Inside 'bull camp' at N
a) (T) level (E) Localised trampling (L) ranch

b) (C) 10YR 7/2 (T) sandy (S) loose sand over brittle crust (L) medium (B) medium (M) Dry

c) (V) Scattered shrubs and trees. Trees c. 5-7m high, shrubs c. 1.5-2m high. Grass brown and dry.
Quadrat 1
(BC) 14 (2.8%)
(T) 4
(C) *A.tortilis* 2
L.nelsii 1
B.albitrunca 1
(S) 12
(C) *Grewia* sp. 9
T.sericea 3
Quadrat 2
(BC) 6 (1.2%)
(T) 3
(C) *A.fleckii* 1
B.albitrunca 1
A.tortilis 1
(S) 12
(C) *Grewia* sp. 4
A.erubescens 1
Combretum sp. 1
R.tenuinerus 1
A.tortilis 2
A.fleckii 1

Site 28 / Inside eastern 'bull camp' at L
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 7/1 light grey (T) sandy (S) brittle crust (L) medium/high (B) medium/low (M) Dry

c) (V) Scattered shrubs and trees. Shrubs c. 1.5-2m high, trees c. 5m. Grass dry with few scattered green clumps.
Quadrat 1
(BC) 19 (3.8%)
(T) 1
(C) *T.sericea*
(S) 14
(C) *Grewia* sp. 3
A.erubescens 3
T.sericea 4

D.cinerea 4
Quadrat 2
(BC) 17 (3.4%)
(T) 4
(C) T.sericea 4
(S) 9
(C) T.sericea 3
Grewia sp. 1
D.cinerea 3
R.tenuinerus 1
Unidentified 1

Site 29 / Inside western 'bull camp' at L
a) (T) level (E) no evidence of disturbance (L) ranch

b) (C) 10YR 7/2 light grey (T) sandy (S) loose sand over brittle crust
(L) medium/low (B) medium (M) Dry

c) (V) Open shrubland with scattered trees. Shrubs c.1.5-2m high, with Pluchea sp. in ground layer. Grass dry except few scattered clumps of green.
Quadrat 1
(BC) 12 (2.4%)
(T) 0
(S) 15
(C) D.cinerea 1
Grewia sp. 9
A.erubescens 1
Combretum sp. 2
Unidentified 2
Quadrat 2
(BC) 13 (2.6%)
(T) 0
(S) 22
(C) D.cinerea 12
A.tortil^is 1
Grewia sp. 6
A.erubescens 3

Site 30 / Outside ranch at 2500 paces from Q, south along cutline.
a) (T) level (E) Trampling over whole area (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) loose sand over brittle crust
(L) low (B) high (M) Dry

c) (V) Scattered shrubs and trees. Shrubs c.2-3m high, trees c.4-5m.
Quadrat 1
(BC) 6 (1.2%)
(T) 1
(C) A.erubescens 1
(S) 12
(C) B.albitrunca 2
Grewia sp. 6
Unidentified 5
Quadrat 2
(BC) 3 (0.6%)
(T) 1

(C) <u>L.nelsii</u> 1
(S) 16
(C) <u>A.erubescens</u> 3
<u>R.tenuinerus</u> 1
<u>Grewia</u> sp. 5
<u>B.albitrunca</u> 2
Unidentified 5

Site 31 / Outside ranch at 1100 paces from Q, south along cutline.
a) (T) level (E) localised trampling (L) common grazing

b) (C) 10YR 7/1 (T) sandy (S) loose sand over c.0.5cm crust (L) medium/low (B) medium/high (M) Dry

c) (V) Scattered shrubs and very scattered trees. Shrubs c.1.5-2m high. Grass dry and brown.
Quadrat 1
(BC) 6 (1.2%)
(T) 0
(S) 7
(C) <u>Grewia</u> sp. 2
<u>D.cinerea</u> 1
<u>C.gratissimus</u> 2
<u>A.tortillis</u> 2
Quadrat 2
(BC) 4 (0.8%)
(T) 1
(C) <u>A.tortillis</u>
(S) 15
(C) <u>C.gratissimus</u> 6
<u>D.cinerea</u> 1
<u>A.mellifera</u>
<u>A.tortillis</u> 1
<u>Grewia</u> sp. 2
Unidentified 3

Sites 32 33 34 / Outside ranch at H, at 100,250,350 paces from H, on an extension of the line H - I.
a) (T) level (slight depression at site 32) (E) no evidence of disturbance, small amount of trampling around 32. (L) common grazing

b) (C) 10YR 5.5/1 grey(32), 10YR 4/1 dark grey (33,34) (T) sandy with fine organic material (S) loose sand (L) high - very high (B) low - very low (M) Dry

c) (V) Open floodplain grassland with sedges. Stalks up to 1.5m tall. Grass fairly green ,but turning brown.
Site 32
Quadrat 1
(BC) 32 (6.4%)
Quadrat 2
(BC) 34 (6.8%)
Site 33
Quadrat 1
(BC) 42 (8.4%)
Quadrat 2
(BC) 37 (7.4%)

Site 34
Quadrat 1
(BC) 39 (7.8%)
Quadrat 2
(BC) 37 (7.4%)

Sites 35 36 37 / Area of bush clearance in paddock 1. Along line E - A, at 200,500,800 paces from E.
Site 35
a) (T) gently sloping (E) Trampling over whole site (L) ranch

b) (C) 10YR 6/2 light brownish grey (T) sandy (S) loose sand (L) medium /low (B) medium/high (M) Dry

c) (V) Open ground, seedlings of common species, few large woody plants. Grass and brown.
Quadrat 1
(BC) 3 (0.6%)
(T) 0
(S) 3
(C) A.tortilis 1
A.erubescens 1
C.mopane 1
Quadrat 2
(BC) 9 (1.8%)
(T) 0
(S) 0

Site 36
a) (T) level (E) trampling over whole area (L) ranch

b) (C) 10YR 7/3 very pale brown (T) sandy (S) loose sand (L) low (B) high (M) Dry

c) (V) Very open, a few scattered shrubs. Grass poor and dry. All shrubs <1m high.
Quadrat 1
(BC) 7 (1.4%)
(T) 0
(S) 4
(C) A.erubescens 1
A.tortilis 1
A.mellifera 1
Grewia sp. 1
Quadrat 2
(BC) 4 (0.8%)
(T) 0
(S) 4
(C) D.cinerea 1
A.tortilis 1
Grewia sp.1
Unidentified 1

Site 37
a) (T) level (E) trampling over whole area (L) ranch

b) (C) 10YR 7/1 light grey (T) sandy (S) loose sand (L) very low

(B) high (M) Dry

c) (V) A few scattered shrubs and seedlings. Very little grass.
Shrubs up to c.1.5m high.
Quadrat 1
(BC) 2 (0.4%)
(T) 0
(S) 2
(C) D.cinerea 1
A.erioloba 1
Quadrat 2
(BC) 1 (0.2%)
(T) 0
(S) 1
(C) Pluchea sp. 1

Sites 38 39 40 / From N, north along cutline towards Maun and RTC crossroad. RTC crossroad to N = 3600 paces. Sites 38, 39 and 40 at 3400, 2400 and 1400 paces from N.

Site 38
a) (T) level (E) localised trampling (L) common grazing

b) (C) 10YR 7/2 (T) sandy (S) loose veneer of sand over crust c. 0.5cm (L) low (B) high (M) Dry

c) (V) Scattered shrubs and trees. Shrubs c. 1-2.5m high, trees c.4-5m.
Quadrat 1
(BC) 2 (0.4%)
(T) 4
(C) L.nelsii 1
T.sericea 3
(S) 17
(C) Grewia sp. 8
D.cinerea 5
A.erubescens 4
Quadrat 2
(BC) 1 (0.2%)
(T) 5
(C) L.nelsii 1
T.sericea 4
(S) 15
(C) Grewia sp. 4
A.erubescens 4
L.nelsii 2
T.sericea 2
D.cinerea 3

Site 39
a) (T) level (E) trampling over whole area (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) loose sand (L) medium/low (B) medium/high (M) Dry

c) (V) Dense shrubland with scattered trees. Shrubs to distinct level c. 2m high. Grass dry and brown. D.cinerea thicket.

Quadrat 1
(BC) 5 (1.0%)
(T) 0
(S) 32
(C) Grewia sp. 1
D.cinerea 31
Quadrat 2
(BC) 8 (1.6%)
(T) 1
(C) L.nelsii 1
(S) 21
(C) Grewia sp. 1
B.albitrunca 2
D.cinerea 15
L.nelsii 1

Site 40

a) (T) level (E) localised trampling (L) common grazing

b) (C) 10YR 7/2 light grey (T) sandy (S) veneer of loose sand over brittle crust (L) medium (B) medium (M) Dry

c) (V) Fairly open, dense in patches. Shrubs c.1.5-2.5m high. Trees scattered c.5m high. Grass dry and brown.
Quadrat 1
(BC) 9 (1.8%)
(T) 1
(C) Unidentified 1
(S) 13
(C) D.cinerea 2
Grewia sp. 6
A.erubescens 3
A.anthelmintica
Unidentified 1
Quadrat 2
(BC) 7 (1.4%)
(T) 2
(C) L.nelsii 1
B.albitrunca 1
(S) 13
(C) A.erubescens 1
Grewia sp. 6
D.cinerea 4
Unidentified 2

Appendix B

Summary of ground data collected at Tsetseku Ranch (1983).

No.Tr = Number of trees rooted in the quadrat.
No.Sh = " " shrubs " " " " .
Wd/ha = Woody plants per hectare calculated from data for each quadrat.
BC% = Percentage basal cover.
Area type = Site type based on vegetation.

Area types - Ac = Acacia depression.
Md = Mixed tree and shrub.
Ts = *Terminalia sericea*.
Tm = *T. sericea*/mixed.
Dc = *Dichostachys cinerea*.
Mo = Molapo grassland.
Bc = Bush clearance area.

Site	Quad.	No.Tr	No.Sh	Wd/ha	BC%	Area type
(25 m x 10 m quadrats)						
1	1	0	21	840	4.4	Md
	2	1	16	680	2.4	Md
2	1	7	15	600	3.8	Md
	2	14	6	240	3.0	Md
3	1	1	32	1320	4.2	Md
	2	0	33	1320	5.4	Md
4	1	0	16	640	1.4	Md
	2	0	28	1120	2.8	Md
5	1	1	20	840	1.0	Ac
	2	1	30	1240	0.8	Ac
6	1	0	21	840	2.0	Md
	2	0	32	1280	1.2	Ts
7	1	3	17	800	3.6	Ac
	2	3	14	680	4.2	Ac
8	1	2	14	640	1.4	Ac
	2	2	9	440	0.2	Ac
9	1	1	29	1200	4.0	Md
	2	0	25	1000	3.8	Md
10	1	0	0	0	8.4	Mo
	2	0	0	0	9.2	Mo
11	1	1	0	40	9.6	Mo
	2	0	0	0	8.8	Mo
12	1	4	0	160	5.6	Mo
	2	2	0	80	5.4	Mo
13	1	0	15	600	2.2	Md
	2	0	12	480	2.4	Md
14	1	0	19	760	2.2	Md
	2	1	23	960	2.6	Md
15	1	3	15	720	2.2	Md
	2	0	14	560	2.4	Md
16	1	1	14	600	3.2	Md
	2	2	13	600	3.0	Md

Site	Quad.	No.Tr	No.Sh	Wd/ha	BC%	Area type
17	1	0	20	800	4.0	Tm
	2	0	18	720	3.8	Tm
18	1	1	18	760	1.8	Md
	2	1	23	960	2.0	Md
19	1	0	21	840	1.2	Tm
	2	0	23	920	1.0	Tm
20	1	0	13	520	3.2	Ac
	2	0	13	520	3.0	Ac
21	1	0	25	1000	1.6	Ac
	2	0	14	560	3.2	Ac
22	1	1	15	640	0.6	Ts
	2	4	15	760	2.0	Ts
23	1	0	21	840	2.0	Md
	2	1	15	640	2.4	Md
24	1	0	26	1040	1.8	Tm
	2	1	20	840	1.8	Tm
25	1	0	25	1000	2.0	Md
	2	2	20	880	1.8	Md
26	1	4	11	600	1.2	Tm
	2	1	14	600	1.4	Tm
27	1	4	12	640	2.8	Md
	2	3	12	600	1.2	Md
28	1	1	14	600	3.8	Tm
	2	4	9	520	3.4	Tm
29	1	0	15	600	2.4	Md
	2	0	22	880	2.6	Md
30	1	1	12	520	1.2	Ac
	2	1	16	680	0.6	Ac
31	1	0	7	280	1.2	Ac
	2	1	14	600	0.8	Ac
32	1	0	0	0	6.4	Mo
	2	0	0	0	6.8	Mo
33	1	0	0	0	8.4	Mo
	2	0	0	0	7.4	Mo
34	1	0	0	0	7.8	Mo
	2	0	0	0	7.4	Mo
35	1	0	3	120	0.6	Bc
	2	0	0	0	1.8	Bc
36	1	0	4	160	1.4	Bc
	2	0	4	160	0.8	Bc
37	1	0	2	80	0.4	Bc
	2	0	1	40	0.2	Bc
38	1	4	17	840	0.4	Tm
	2	5	15	820	0.2	Tm
39	1	0	32	1280	1.0	Dc
	2	1	21	880	1.6	Dc
40	1	1	13	560	1.8	Md
	2	2	13	600	1.4	Md

Site	Quad.	No.Tr	No.Sh	Wd/ha	BC%	Area type
(10 m x 30 m cover diagram quadrats)						
1	-	4	6	333	-	Ac
2	-	4	15	633	-	Ac
3	-	2	7	300	-	Ac
4	-	2	11	433	-	Ac
1	-	3	30	1100	-	Md
2	-	0	29	967	-	Md
3	-	2	34	1200	-	Md
1	-	7	34	1500	-	Ts
2	-	7	27	1133	-	Ts
3	-	6	35	1367	-	Ts
4	-	10	27	1233	-	Ts

Appendix C

Plant species cited in the thesis.

Grasses, sedges and reeds.

Aristida congesta Roem . et Schult.
Aristida hordeacea Kunth.
Aristida scabrivalvis Hackel.
Cenchrus cilliaris L.
Chloris virgata Sw.
Cynodon dactylon (L) Pers.
Cyperus spp.
Digitaria aegyptium (L) Beauv.
Digitaria milanjiana (Rendle) Stapf.
Echinohloa sp.
Enneopogon brachystachus Stapf.
Eragrostis rigidior Pilger.
Eragrostis superba Peyr.
Megaloprotachne albescens C .E . Hubbard.
Miscanthidium teretifolium (Stapf.) Stapf.
Oropetium capense Stapf.
Panicum repens L.
Phragmites mauritanus Kunth.
Sipagrostis uniplumis Licht.
Sporobolus spicata Kunth.
Tragus racemosus (L) Steud.
Urochloa mosambicensis (Hack) Dandy.

Trees and shrubs.

Acacia arenaria Schinz.
Acacia ataxacantha DC.
Acacia erioloba E. Meyer.
Acacia erubescens Welm. ex Oliv.
Acacia fleckii Schinz.
Acacia mellifera (Vahl) Benth.
Acacia nebrownii Burtt Davy
Acacia nigrescens Oliv.
Acacia sieberana DC.
Acacia tortilis (Fossk.) Hayne.
Albizia anthelmintica (A.Rich.) Brongn.
Boscia albitrunca (Burch.) Gilg & Ben.
Boscia foetida Schinz.
Catophractis alexandri D . Don.
Colophospermum mopane (Kirk ex Benth .) Kirk ex J. Leon.
Combretum imberbe Wawra.
Commiphora mollis (Oliv.) Engl.
Commiphora pyracanthoides Engl.
Croton gratissimus Burch.
Croton megalobotrys Muell.Arg.
Dichrostachys cineria (L.) Wight & Arn.
Ficus sycamorus L.
Garcinia livingstonei T . Anders.
Grewia bicolor Juss.
Grewia flava DC.

Grewia flavescens Juss.
Hyphaene ventricosa Kirk
Kirkia sp.
Lonchocarpus capassa (Klotzsch) Rolfe
Lonchocarpus nelsii (Schinz) Schinz ex Heering & Grimme.
Markhamia acuminata K . Schum.
Rhus tenuinervis Engl.
Syzygium cordatum Hochst.
Terminalia prunioides Laws.
Terminalia sericea Burch. ex DC.
Ximenia americana L.
Zizyphus mucronata Willd.

Herbaceous plants with persistent 'woody' stem base (suffrutescent plants).

Leucosphaerea bainesii Gilq.
Plinthus karooicus Verdoorn.
Pluchea leubnitzii (O. Kuntze) N. E. Br.
Sesbania sp.

Reference works used during ground survey; Miller (1948), Field (1976), Coates-Palgrave (1977), Palmer (1977), Timberlake (1980).

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