THE USE OF DIGITALLY INTERPRETED SATELLITE IMAGERY, WITH SPECIAL REFERENCE TO TOPOGRAPHICAL SHADOW EFFECTS, AS AN AID TO VEGETATION MAPPING IN THE HOTTENTOTS HOLLAND MOUNTAIN CATCHMENT AREA OF THE WESTERN CAPE PROVINCE.

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ABSTRACT

This report includes a summary account of the operation of the LANDSAT 2 satellite and describes some of the procedures for extracting information, relating to vegetation, from digital imagery. The effect of topographic shadow on the imagery is explained and a short discussion of mountain fynbos, the natural vegetation of the mountains of the Western Cape Province of South Africa, is included.

The report explains the methods used to estimate the amount of shadow on the imagery of the study area and to investigate the potential of various spectral band ratios for giving useful management information.

It was found that approximately seventeen percent of the image of the Hottentots Holland Mountain Catchment Area is affected by topographic shadow. No meaningful information could be extracted from the shadowed areas, by digital image processing. Band ratioing did however, result in strong correlations between spectral values and vegetation height, percentage cover and biomass, as well as leaf surface area, veld condition and aspect, for sun illuminated areas.

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GLOSSARY.

APOGEE The maximum distance between a satellite in an eliptical orbit and the body around which it is orbiting.

AZIMUTH The geographic orientation of a line given as an angle measured clockwise from north.

BAND A wavelength interval in the electromagnetic spectrum. For example, in LANDSAT the bands designate specific wavelength intervals at which images are acquired.

BIT In digital computer terminology, this is a binary digit that is an exponent of the base 2.

CCT Computer compatible tape; the magnetic tape upon which the digital data for LANDSAT MSS images are recorded.

IMAGE The representation of a scene as recorded by a remote sensing system. Although image is a general term, it is commonly restricted to representations acquired by nonphotographic methods.

NOISE Random or repeptitive events that obscure or interfere with the desired information.

PERIGEE The minimum distance between the satellite in an eliptical orbit and the body around which it is orbiting.

PIXEL In a digitized image this is the area on the ground represented by each digital value.

POINT SPREAD FUNCTION This function of an image system describes the resulting spatial distribution of grey shade when the input to the system is some well defined object, (point) much smaller than the width of the spread function.

RAYLEIGH SCATTERING Selective scattering of light by particles in the atmosphere that are small relative to the wavelength of light. The scattering is inversely proportional to the fourth power of the wavelength.

SIGNATURE A characteristic, or combination of characteristics, by which a material or an object may be identified on an image or photograph.

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CHAPTER ONE

1. INTRODUCTION.

This project was designed to satisfy two main criteria. Firstly, it was to be a didactic exercise in remote sensing and digital image processing. Secondly, it was to be a pilot study for the Directorate of Forestry, into the utilization of LANDSAT multispectral imagery in the management of fynbos mountain catchment areas. The results of this study will be used to plan more goal-directed research into the operational utilization of remote sensing products in the management of fynbos mountain catchment areas.

This study was therefore approached in a way where the results would give indications of the potential applications of LANDSAT imagery in the management processes.

As topographical shadow was expected to have an adverse effect on the quality of the imagery, special attention was given to evaluating this and possible ways of overcoming these effects were investigated.

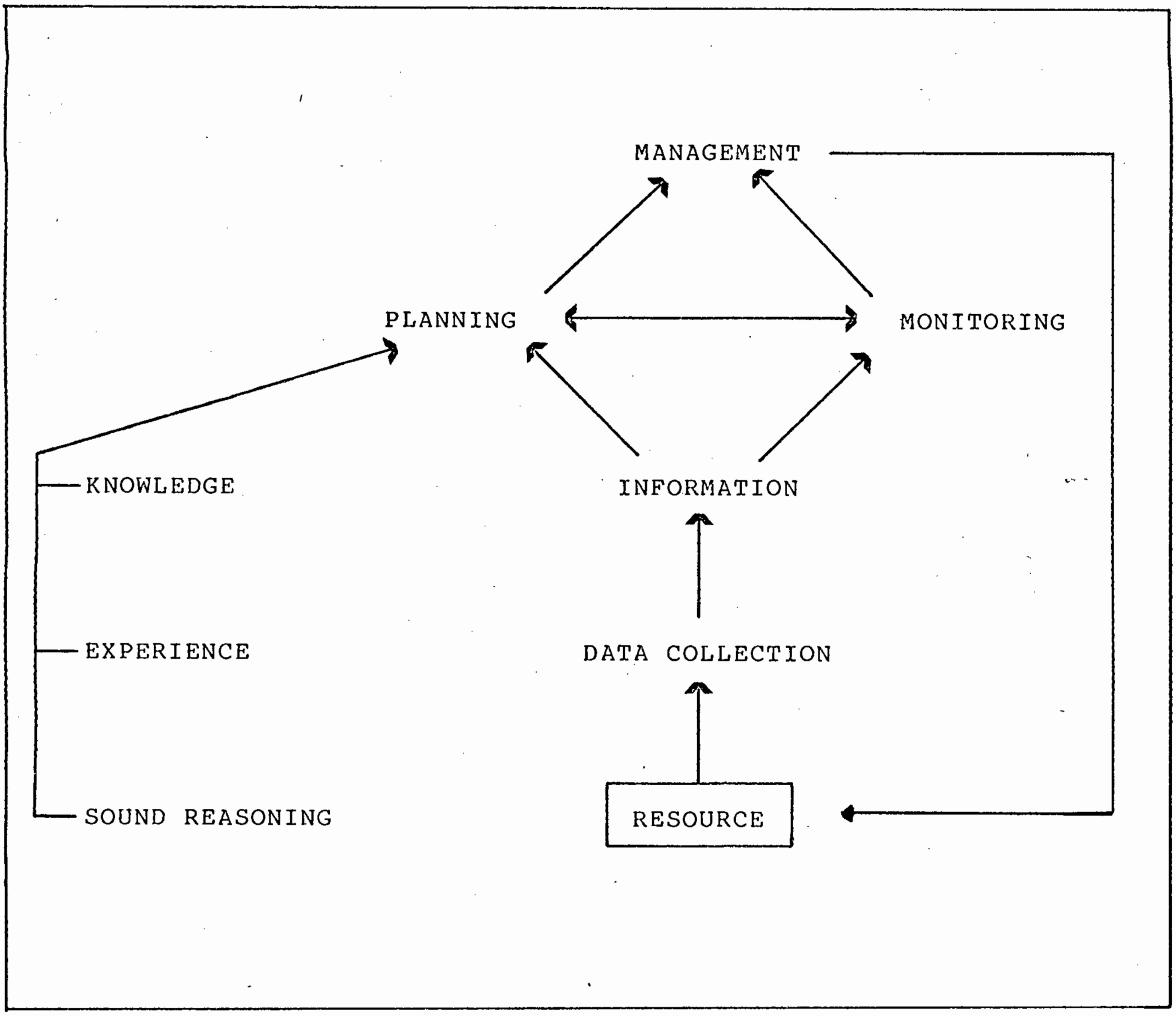
1.1. BACKGROUND

"It is usually the bad management of the watershed that is destroying our water resources" (Odum 1971).

Sound ecological management is necessary to ensure the sustainability of any renewable natural resource. In South Africa, where one of the limited renewable natural resources is water, sound management of the country's mountain catchment areas is essential.

Planning and monitoring are two devices used in management. The key to sound planning lies in the acquisition and evaluation of information about the management unit. Monitoring contributes to the collection of knowledge and experience, and is needed for evaluating executed management decisions. The gathering of data and their transformation into information is therefore one of the major tasks of any management process (Fig 1-1).

Figure 1-1. THE RESOURCE MANAGEMENT PROCESS.



One means of obtaining information for large management units, is by remote sensing.

Remote Sensing has been defined by different authors in different ways. Swain (1978) defines it as "the science of deriving information about an object from measurements made at a distance from the object, ie. without actually coming in contact with it. The quantity most frequently measured in present day remote sensing systems, is the electro-magnetic energy (EME) emanating from the object of interest". Hoffer (1971) states it as "the science involved with the gathering of data about the earth's surface or near surface environment, through the use of a variety of sensor systems that are usually borne by aircraft or spacecraft and the processing of these data into information useful for the understanding and managing of man's environment". In summarizing these definitions, remote sensing is the science of:

1. measuring electromagnectic energy emanating from an object without being in actual contact with the object, ie. at a distance from the object.
2. converting the measured electromagnetic energy data into information useful for man's understanding and managing of his environment.

The Directorate of Forestry in South Africa is responsible for the management of large areas of natural vegetation. At present this totals 1.4 million hectares and is expected to increase to 2.0 million hectares during the next ten years (Directorate of Forestry,1983). As detailed management planning of most of these areas only started in the 1970's (Department of Forestry,1971), it can be stated that the planning processes and information gathering methods are still in an evolutionary stage. At present information for management planning is gathered by three means:

1. from published literature and other available written records and reports.
2. through field surveys and personal interviews.
3. through the visual interpretation of the most recent available black and white aerial photographs.

These methods have not always been satisfactory, because of limitations of time, funds and personnel. Insufficient experience and training in photo-interpretation and obsolete data have also been contributory factors.

Recent technological advances in the fields of remote sensing, space exploration and computerized data processing, have made it possible to acquire measurements of electromagnetic energy, emanating from the earth's surface, through sensors on board spacecraft in orbit around the earth. This data is available, relatively inexpensively, as numerical measurements (digital data) and can be speedily and accurately transformed into useful information with the aid of a digital computer. The advantage of these developments is the relatively low costs of obtaining recent and detailed information for large management areas on a repetitive basis. This information is therefore suitable for use in both the planning and monitoring processes.

This project was initiated to investigate the possible utilization of the LANDSAT satellite's multispectral scanner (MSS) data, in the management of the natural vegetation in the mountainous areas of the Western Cape Province of South Africa. However, in mountain areas, topographical shadows complicate the interpretation of the imagery.

1.2. THE HYPOTHESIS.

The hypothesis to be tested is that "LANDSAT multispectral scanner digital imagery is a useful source of information for the planning, monitoring and management functions of mountain catchment areas of the Fynbos Biome, inspite of the presence of topographical shadows on the imagery". The following questions were addressed by the study.

1. How much topographic shadow is there on an image of an average mountain catchment area?
2. Can any useful information be obtained from the shadowed areas?
3. Can the quality of the information be improved by manipulating the data in certain ways, ie. by ratioing the data of different spectral bands?
4. What types of useful information can be obtained from the imagery?

CHAPTER TWO

2. THE SATELLITE AND ITS SENSOR.

Canby (1983) reports that in 1957 the first man made satellite, "Sputnik 1" entered space. By 1983 fourteen thousand man made objects had been launched into space, two thirds of which have re-entered the earth's atmosphere and been burnt up. It is estimated that at present, there are approximately 290 operable spacecraft circling the earth, owned by 21 different nations.

The following information is summarized from work by Piper and Scogings (1983), Slater (1980) and Taranik (1978).

In 1963 with the launching of the first "Nimbus" weather satellite, the idea of earth observation satellites for the gathering of environmental data was first thought of. It was however not until 23 July 1972, that the first LANDSAT satellite (originally called ERTS, ie. Earth Resource Technology Satellite) was put into orbit. Its planned lifespan was one year, but it only ceased operating on 10 January 1978. A second satellite, LANDSAT 2, was launched on 22 January 1975. This satellite was identical to the previous model and operated for seven years. It was removed from service on 25 February 1982. The imagery from this satellite has been used in this project. Since LANDSAT 2, two further satellites in this series have been put into space. LANDSAT 3 operated between 5 March 1978 and 30 March 1982. LANDSAT 4, the most recent vehicle in this series, is of a different design. It has a lower orbit and carries the new thematic mapper sensor, resulting in imagery with a much improved spatial and spectral resolution. Table 2-1 summarizes the operation of earth observation satellites.

The discussion that follows applies to the first three LANDSAT satellites, and specifically to LANDSAT 2, used in this project.

Table 2-1. ENVIRONMENTAL OBSERVATION SATELLITES.

SATELLITE	AGENCY	LAUNCH	TERMINATION	STATUS *
LANDSAT 1	NASA	1972	1978	EXPERIMENTAL
LANDSAT 2	NASA	1975	1982	EXPERIMENTAL
LANDSAT 3	NASA	1978	1982	EXPERIMENTAL
LANDSAT 4	NASA	1982	--	PRE-OPERATIONAL
SPOT	FRANCE	1984	--	PRE-OPERATIONAL

*EXPERIMENTAL = data flow can be interrupted at any time.

*PRE-OPERATIONAL = data flow is more reliable, but can be interrupted.

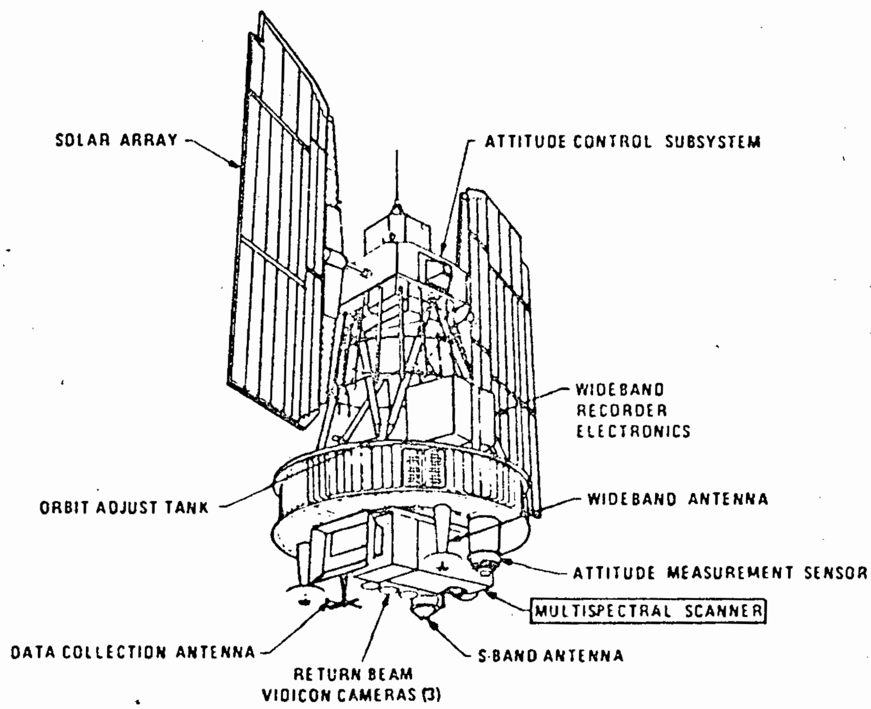
(NERC,1982)

2.1. LANDSAT 2

This discussion is based on work reported by Piper and Scogings(1983), Slater(1980) and Taranik(1978).

Figure 2-1. NIMBUS DESIGN WITH LANDSAT CONFIGURATION.

(NASA,1976)



LANDSAT 2 is based on the design of the "Nimbus" weather satellite (Fig 2-1). It was launched by the National Aeronautics and Space Administration of America (NASA) on 22 January 1975. The orbit of this spacecraft is a near polar, sun-synchronous orbit at an altitude of approximately 900 kilometres (Table 2-2). The inclination of the orbit at 99.21 degrees clockwise to the equator (Fig 2-2) places the satellite in a sun-synchronous orbit and causes the angle between the sun, the orbital plane of the earth and the orbital plane of the satellite to remain constant at 37.5 degrees (Fig 2-3). The inclination of 9,21 degrees from the pole (90 degrees) causes the satellite orbital plane to precess by nearly 1 degree per day to the east, thus compensating for the earth's eastward rotation of 360 degrees per year (365 days) around the sun. The effect of this is that the satellite crosses the same point on the earth's surface at approximately the same local time with each overpass. This ensures that the sun's irradiating conditions are very similar for each satellite crossing, the seasonal migration of the sun being the only factor causing a change in these conditions. Thus imagery captured on the same day each year for the same place will have almost identical radiation conditions. The result of this is that adjacent images can easily be mosaiced together without having to compensate for different brightness conditions.

A further advantage of a near polar orbit is that most of the earth can be imaged from the spacecraft. In the case of LANDSAT 2 only those areas north and south of 82 degrees latitude cannot be imaged.

Figure 2-2. INCLINATION OF LANDSAT ORBIT TO MAINTAIN SUN-SYNCHRONOUS ORBIT. (Taranik,1978)

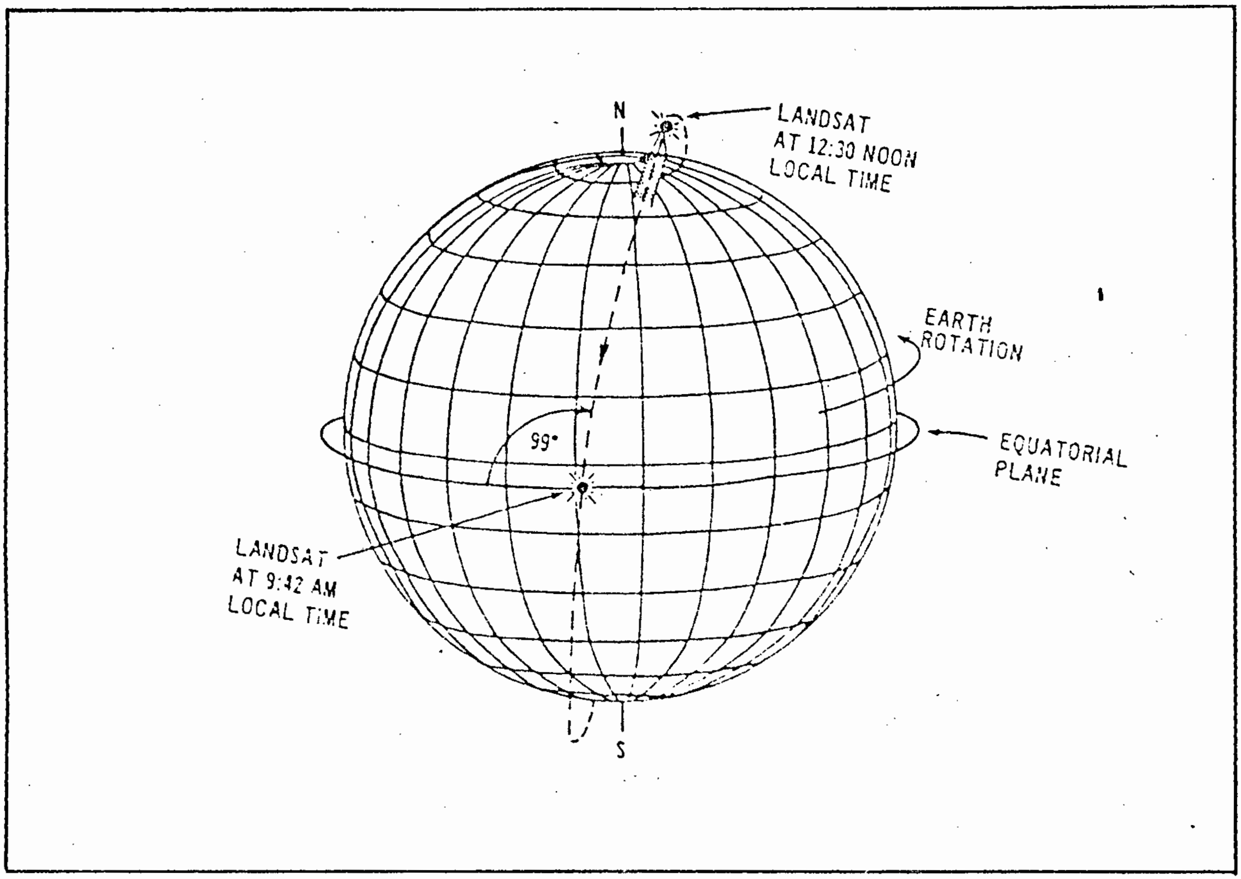
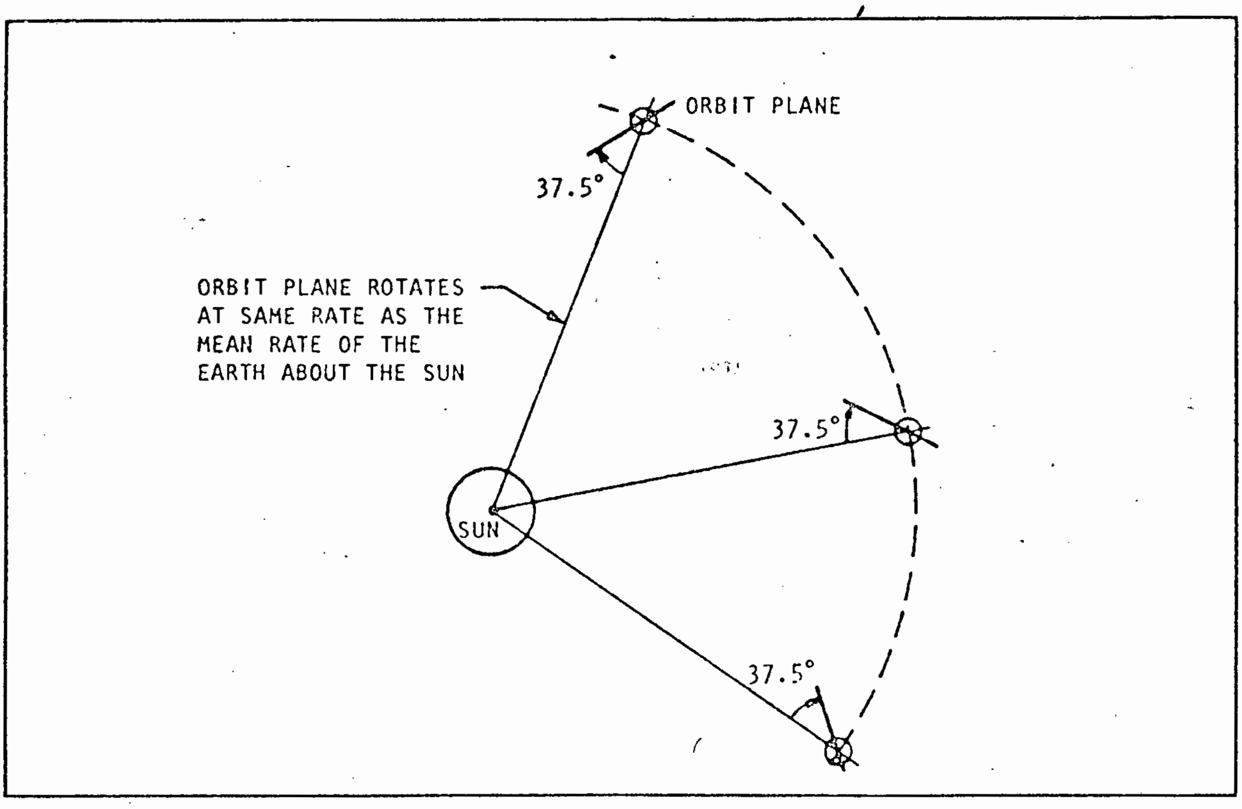


Figure 2-3. MOTION OF ORBIT PLANE IN SUN-SYNCHRONOUS ORBIT. (Nash,1972)



The selected orbit results in the satellite completing an orbit every 103,15 minutes, during which time the earth has rotated 2 760 kilometres at the equator. This means that during one day (24 hours), the satellite completes 14 orbits. On the fifteenth orbit, it images that swath of the earth's surface falling on the western side of the swath it imaged 24 hours earlier (Fig 2-4). The orbit also results in the satellite passing over the same point on the earth's surface every eighteenth day. Thus, weather permitting, imagery for monitoring purposes can be obtained every eighteenth day.

The orbit of the satellite can be divided into two parts. A north bound path (ascending mode) during which its moves from near the south pole up to the north pole, over the part of the earth in darkness. During this time no imaging is possible. On the south bound section (descending mode) of the orbit, it passes over that part of the earth that falls in daylight and imaging is possible. The ground speed at which the satellite moves is 6.46 kilometres per second. (Piper and Scogings,1983; Slater,1980; Taranik,1978)

<u>Figure 2-4.</u> TYPICAL LANDSAT GROUND TRACE FOR ONE DAY.

(only southbound passes shown) (NASA,1972)

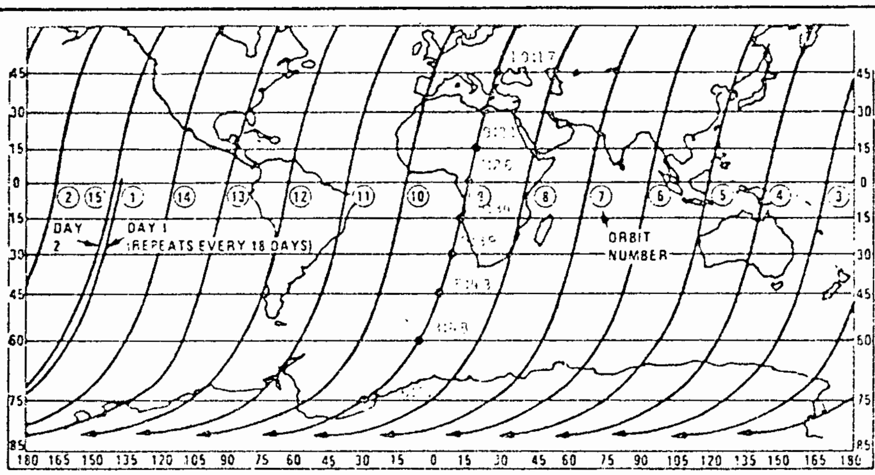


Table 2-2. LANDSAT ORBITAL PARAMETERS.

APOGEE (furthest point from earth)	917 km
PERIGEE (nearest point to earth)	898 km
INCLINATION	99 degrees
PERIOD	103 minutes
ORBITS PER DAY	14
GROUND SPEED	6.456 km/sec
	387.36 km/min
	23 242 km/hr
PRECESSION PER DAY	1 degree
LOCAL TIME OF DECENDING MODE	09h30
GLOBAL COVERAGE CYCLE	18 days
DISTANCE BETWEEN TRACKS (equator)	159.38 km
(Cape Town)	132 km

(after Piper and Scogings,1983).

2.2. THE SENSORS.

The LANDSAT 2 satellite carries three different data collection systems. They are :

1. A three spectral band multispectral return beam vidicone television system.
2. A four spectral band multispectral scanner, which is discussed in more detail at a later stage.
3. A data collection platform that collects environmental data transmitted to it from automatic monitors located in remote regions on earth.

2.2.1. THE MULTISPECTRAL SCANNER. (MSS)

The imagery used in this project was captured by the MSS and is therefore discussed in more detail below.

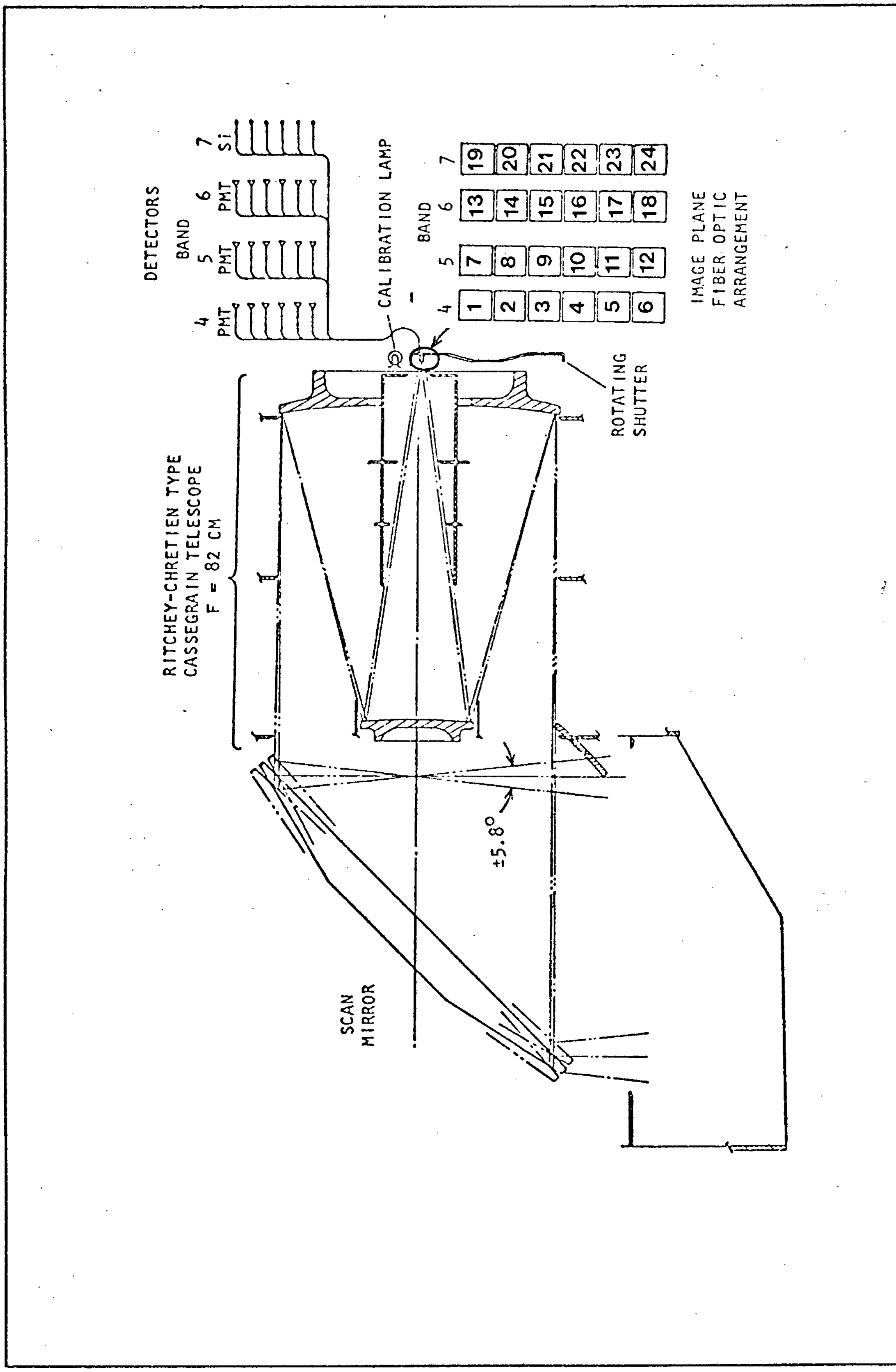
It comprises of two main parts, the scanner itself with approximate dimensions of 36 x 38 x 90 centimetres and weighs 47.6 kilograms and the multiplexer (data logger), with dimensions of 10 x 15 x 17 centimetres and weighs 2.7 kilograms. The system is powered by the solar panels of the satellite.

2.2.1.1. THE MULTISPECTRAL SCANNER LAYOUT.

A diagramatic layout of the scanner is given in Fig 2-5. Rays of electromagnetic energy (EME) reflected from the earth, strike the flat primary mirror of the scanner. This mirror oscillates across the track of the spacecraft, through an arc of 5.8 degrees at a frequency of 13.62 Hertz, (cycles per second), giving a total field of coverage of 11.6 degrees (a mirror rotated through an angle causes the reflected rays to change through twice the rotated angle, ie. 2 x 5.8 = 11.6). An angle of 11.6 degrees subtends an arc on the earth's surface of 185 kilometres, if the apex of the angle is at an altitude of 910 kilometres above the earth, the nominal height of the MSS sensor. This width is the across track distance, ie. the width of the image.

Figure 2-5. LAYOUT OF THE FOUR BAND LANDSAT MSS.

(Slater,1980)



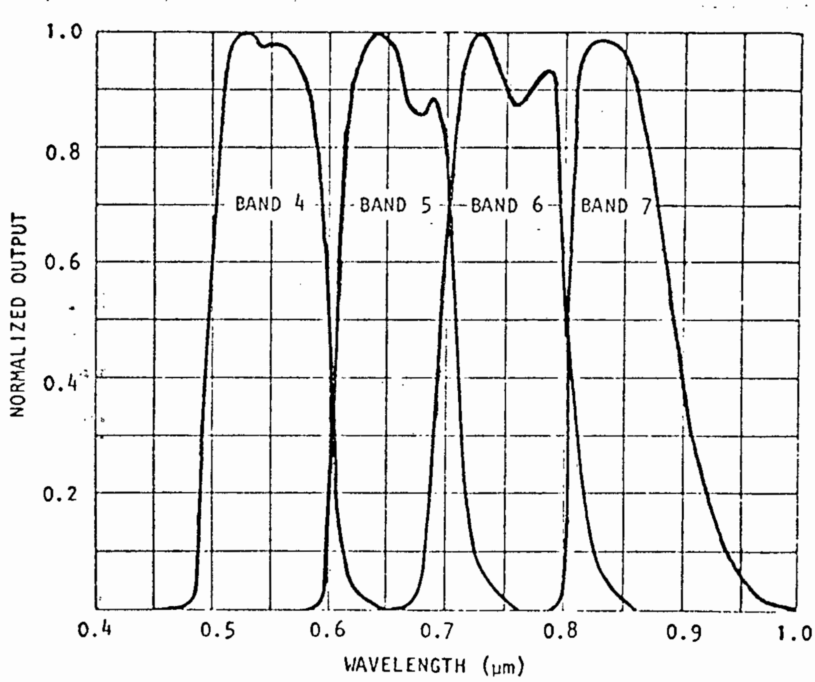
The primary mirror reflects the rays reaching it into the optic telescope of the sensor and the rays are focussed onto four banks of six square-cross-section optical fibres (Fig 2-5). The fibres in each bank are separated from each other by a thin protective coating, resulting in an unsensed region between each fibre of 5.5 metres on the ground. Each fibre covers a rectangle on the ground of 76 x 76 metres, ie. the Instantaneous Field of View (IFOV).

As the mirror sweeps the image over the banks of sensors, it first passes over the six optical fibres of bank number one and lastly over bank number four. Each bank corresponds to one of the four spectral bands sensed by the MSS. The EME falling on the fibres is conveyed up the fibres by total internal reflection, until it is intercepted by an optical filter. These filters allow only those wavelengths of light corresponding to the spectral band designated to that optical fibre to pass through.

The first spectral band (BAND 4, because the data relating to this band is relayed from the satellite to the earth on LANDSAT channel 4) has a wavelength range of 0.5 to 0.6 micrometres and is monitored by the first bank of fibres (fibre numbers 1 to 6). Likewise, the second spectral band (BAND 5, for the same reason) has a wavelength range of 0.6 to 0.7 micrometres and is sensed through the second bank of fibres (numbers 7 to 12). BAND 6 has a wavelength range of 0.7 to 0.8 micrometres and BAND 7 has a range of 0.8 to 1.1 micrometres. These bands are sensed by fibre numbers 13 to 18 and 19 to 24 respectively. The actual response curves of these filters are shown in Fig 2-6 (see also Table 6-1).

After the rays of light have passed through the filters, they fall onto the detectors, which for bands 4, 5 and 6 are photomultiplier tubes and for band 7 are silicon photodiodes. The light causes a voltage of between 0 and 4 volts, proportional to the amount of light striking the detector, to be generated. Every 9.95 microseconds the multiplexer samples this voltage and assigns it a six bit digital value (a value between 0 and 64) proportional to the voltage. This value is then, in the case of imagery of Southern Africa, received by the satellite tracking station at Hartebeesthoek, near Pretoria, where ground processing takes place.

Figure 2-6. THE NOMINAL SPECTRAL RESPONSES OF THE MSS BANDS (Norwood et al,1972)



2.2.1.2. THE SCANNING OPERATION.

As the oscillating mirror scans from west to east across the path of the satellite, imaging is occuring. The mirror is oscillating at a frequency of 13.62 Hz and is covering a swath of 185 kilometres. Sampling by the multiplexer is occuring every 9.95 microseconds. The IFOV of the optical fibre is 76 x 76 metres. Sampling is however occuring after the mirror has moved the image approximately 56 metres. This means that overlap sampling is occuring. This overlap is desirable as it improves the spatial resolution of the imagery in the across track direction. The multiplexer is however recording the sample as a 76 x 76 metre square. Spatial distortion is therefore introduced and must be corrected for. This is done by giving the recorded spectral value a spatial width of 56 metres. It however contains information from a 76 metre width as well as some information from a further 30 metres, caused by the point spread function or "blur circle" of the image forming optics.

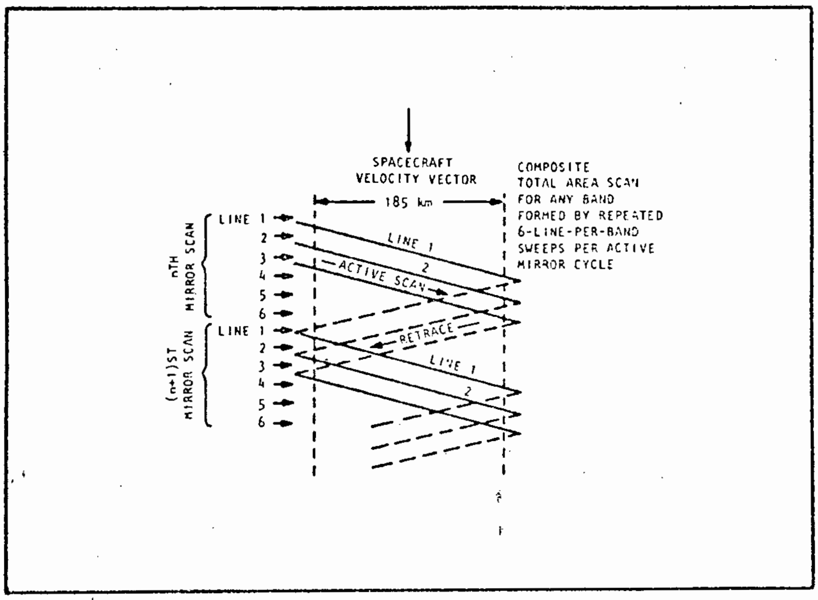
The mirror projects its image over each of the four six fibre optical banks in turn, thus six rows of spectral values in each band are recorded with each oscillation. There are about 3 300 samples in one row.

On the return movement (east to west) the sensor does not actively record data, but the optical fibre ends are exposed to a calibration lamp with a known spectral value. This allows the system to control its spectral calibrations.

In the along track direction the sample dimensions depend on two factors. The IFOV of the optical fibres (76 x 76 metres) and the protective coating between the fibres with a ground distance of 5.5 metres of unsensed region. The ground length of the spectral information, relating to one sample is therefore 81.5 metres, but contains information for only 76 metres plus the "blur circle" contribution from a further 30 metres. The picture element size or PIXEL size for LANDSAT 2 is therefore given as 56 x 81.5 metres (this is often quoted in literature as 56 x 79 metres, the designed size). There are six rows of pixels in each scan (Only three are shown in Fig 2-7). Each pixel has four spectral values, one for each band.

It should also be noted that owing to the movement of the spacecraft, the scan lines are not perpendicular to the path of the craft, but zigzag across it (as shown in Fig 2-7). This slant is removed during ground processing, which restores the geometery of the image. Ground processing also involves other geometric and radiometric processes to improve the geometery and quality of the image. As an image has a set width (185 kilometres), but not a fixed length, the ground processing station usually cuts the image swath off at a fixed length. In South Africa and most other countries, an image has 3 240 samples across and is cut off after 2 340 lines in length (185 x 185 kilometres, or 7 581 600 pixels per image). Another of these processes involves the expanding of the six bit digital value to an eight bit (0 to 255) value. The processed image is then placed on a computer tape with its identification labels and other relevant information. This is dispatched by the ground receiving station to the user as a computer compatible tape (CCT) for image processing. (Slater,1981; Taranik,1978)

Figure 2-7. GROUND SCAN PATTERN OF MSS CHANNELS. (NASA,1972)



CHAPTER THREE

3. DIGITAL IMAGE PROCESSING (DIP).

Image processing can be regarded as any operation carried out on an image once it has been recorded on some medium (Jarman,1981).

Landsat imagery can be presented for information extraction in two forms. An analogue image (photographic print) can be prepared and is interpreted in the conventional, visual manner, using colour, hue and texture to identify and extract information. The second method is to use the numerical image data as stored on the CCT, and to extract the information with the aid of a computer and digital image processing procedures. Owing to the inherent quantitative nature of the LANDSAT imagery, digital image processing is the preferred option and was used in this project.

Digital image processing methods can be grouped into three main categories: image restoration. image enhancement and information extraction. (Sabins,1978)

Image restoration routines allows the image analyst to compensate for data errors, noise and geometric distortions occuring in the imagery. If an image, for example, is found to be geometrically distorted, because of the mode of operation of the scanner, as is the case with LANDSAT MSS, an arithmetical transformation, the affine transformation, can be performed on the data and the correct geometric relationships of the image elements (pixels) to each other can be restored.

Image enhancement routines are performed on an image to emphasize the information content of the image. This is done by making the information more recognizable to the eye. These enhancement routines, such as emphasizing the contrasts in an image or causing the boundaries between different features to stand out, are important when the analyst is examining the imagery visually.

Information extraction routines utilize the decision making capabilities of a computer and are used to extract groups of similar data from the imagery. These groups of data have information content useful to the analyst. Routines such as band ratioing and multispectral classifications, both explained in more detail below, are examples.

Most of these processing routines are to be found in digital image processing systems. The digital image is fed into the system and the analyst is able to perform selected routines on the image and so extract the information he requires. The three major processing algorithms used in this project are described below.

3.1.1. GEOMETRIC CORRECTION BY AFFINE TRANSFORMATIONS.

As the degree of geometric accuracy of an image required by the user is dependant on the scale at which the final mapping product will be produced, not all geometric distortions are removed before the CCT is despatched to the user. Most DIP systems therefore have the means of improving the geometry of an image.

An "affine" routine can, if given certain information, relating to the scene, establish a linear transformation function to improve on the geometry of the scene and to alter its scale. It can also be instructed to calculate polynomial affine transformation functions for accurately relating pixel positions to their true ground surface locations.

To establish the linear transformation function, the programme requires the latitude of the image, the required scale of the output image and the LANDSAT satellite number, from which the imagery was received. As the programme contains the distortion parameters of the specific LANDSAT vehicle, it is able to create the required transformation from this data.

If greater accuracy is required, the polynomial affine transformation functions need to be requested. This transformation operates on the relationship between the cells of two matrices. The one matrix is the image matrix, where the co-ordinates of the pixels are given by the line and column numbers. The other matrix is the earth's surface itself, where the co-ordinates are given by the South African National Geodetic Co-ordinate System. If the image co-ordinates are given as (x,y) and the ground point co-ordinates are given as (u,v), the affine transformation has the form $x = f1 (u,v)$ and $y = f2 (u,v)$, where f1 and f2 are same order polynomials. The programme therefore requires a set of points for which the image co-ordinates and the SA National co-ordinates are known. From this data, it can compute the transformation functions. These functions are then used to create the geometrically corrected image.

Note that the selected points do not have to be contained in the image being transformed, but do have to be from the same data set from which the image came. This means that once the ground control points for an image have been established, they can be used to geometrically correct any sub-image of the original image.

3.1.2. CLASSIFYING AN IMAGE.

Classifying the elements (pixels) of an image into information classes is the most important function of the information extraction routines.

Each pixel has one or more spectral reflectance values, either directly measured by the MSS or created by one or other information extraction routine (eg. band ratioing). The data relating to one pixel can be referred to as the measurement vector for that pixel. From the measurement vector, a subset of measurements are selected, because they correlate well with the information that is being sought. For example, measurements of LANDSAT band 5 and band 7 correlate well with vegetation. These subsets are referred to as feature vectors.

In the image classification process, these feature vectors are grouped into statistically similar classes, giving the information groupings sought by the analyst. It is the analyst's task to select the feature vectors and the success of this selection depends on his experience and training.

The classification procedure is a statistical procedure which can be computerized. It normally involves two steps. The first step is to " train the classifier", the second is to execute the classification with the aid of the trained classifier.

3.1.3. TRAINING THE CLASSIFIER.

A trained classifier contains the signatures or unique statistics of each class it has been trained to recognize. The signature of a class normally consists of the statistics (mean, variance, co-variance) of each of the components, forming the feature vector for that class. If, for example, the red band values and the infra-red band values are selected to form the feature vectors, then the signature for the class vegetation, will consist of the mean spectral value of vegetation in the red band and its standard deviation, as well as the mean infra-red spectral value and its standard deviation, as well as other relevant statistics.

The classification process then stastistically checks the two components of the feature vector (the red value and the infra-red value) of each pixel, against the class signature, and decides whether the pixel belongs to the class or not.

The training of the classifier or the establishing of the class signatures can be done in two ways. Either the supervised approach or the unsupervised approach can be adopted.

3.1.3.1. THE SUPERVISED APPROACH.

This is the simpler of the two approaches and is most suitable for projects, where ground reference data are easily and readily obtainable. For this approach, the area under study must also contain large representative areas of the classes of interest. At least one training area, which is a homogeneous area containing only one information class, from each class of interest is selected and fed into the classifier. The classifier knows that the signature it calculates for each training area, is the signature for the class that training area represents. The classifier is trained and it can continue with the classification process. For this approach, the analyst must be certain that the information classes he chooses, are not spectrally similar, as this will confuse the classifier.

3.1.3.2. THE UNSUPERVISED APPROACH.

This approach is used when the area under study is heterogeneous, and no large areas of the classes of interest exist. It is also used where the collection of ground reference data is difficult or restricted. In this approach the feature vectors are fed into the algorithm and are statistically sorted into spectrally similar groups. These groups must then be checked by the analyst to see if they represent the information classes he is seeking. The signatures of these groups are calculated and supplied to the classifier.

One of the techniques, which is available for the unsupervised approach and forms the basis for a routine used in this project, is the Isodata or Iterative Self Organizing Data Analysis Technique of Ball and Hall (1965). This is an iterative technique of dividing the data into groups and then combining similar groups, and repeating this procedure until the data is divided into suitable clusters.

The procedure starts by selecting, at random, a number of cluster or group centre points. It then divides the data into groups around these points. The averages of the data in these groups are computed and become the new group centre points. For those groups that have a large standard deviation or contain a large number of elements, the centre point is split into two points. If the number of groups are much smaller than the number of classes desired by the analyst, the centre points can also be split. The data are again sorted into groups and the averages of the groups are again computed. The above procedures are also repeated. If it is found that any two centre points are close together after a number of iterations have been done, these two groups are combined into one group with a new centre point. This process of splitting and combining continues until the centre points reach a point of stability. The data groups that result from this process, are regarded as the training groups for which signatures can be calculated and used in the classification process. The above technique demands considerable computing time, it is therefore not practical to submit large images to this process. A set of training areas are selected to reduce this demand. These training areas are selected, so that each area contains more than one information class and all the training areas combined, contain samples of all possible information classes.

3.1.4. THE CLASSIFICATION PROCESS.

This process involves the statistical division of the total data set into information groups or classes, depending on the statistical parameters contained in each group's signature.

The procedure used in this project is based on the Bayes' Maximum Likelihood Decision Rule. This rule decides to place the feature vector (or pixel) (X) into a given class (Wi), if the product of the probability density function p(X/Wi) and the a priori probability p(Wi) of the vector belonging to that class, is a maximum. $X \in Wi$, if and only if, p(X/Wi)p(Wi) is a maximum for all possible Wj, where j = 1 2 3 ...m.

It can be shown (Swain,1978) that this rule evaluates and minimizes the average cost that is incurred, by placing a vector into the wrong class. This minimizing of the average cost, is referred to as the Bayes Optimal.

During the training of the classifier, a signature for each class, was calculated containing various statistics like the mean, variance and the co-variance matrix. From these statistics, the classifier can calculate the probability density function for the class. This signature also contains an estimation of the a priori probability for the class, based on the training data used. The accuracy of the estimation of p(Wi) therefore depends on the representativeness of the selected training areas.

3.2. THE PIPS SYSTEM

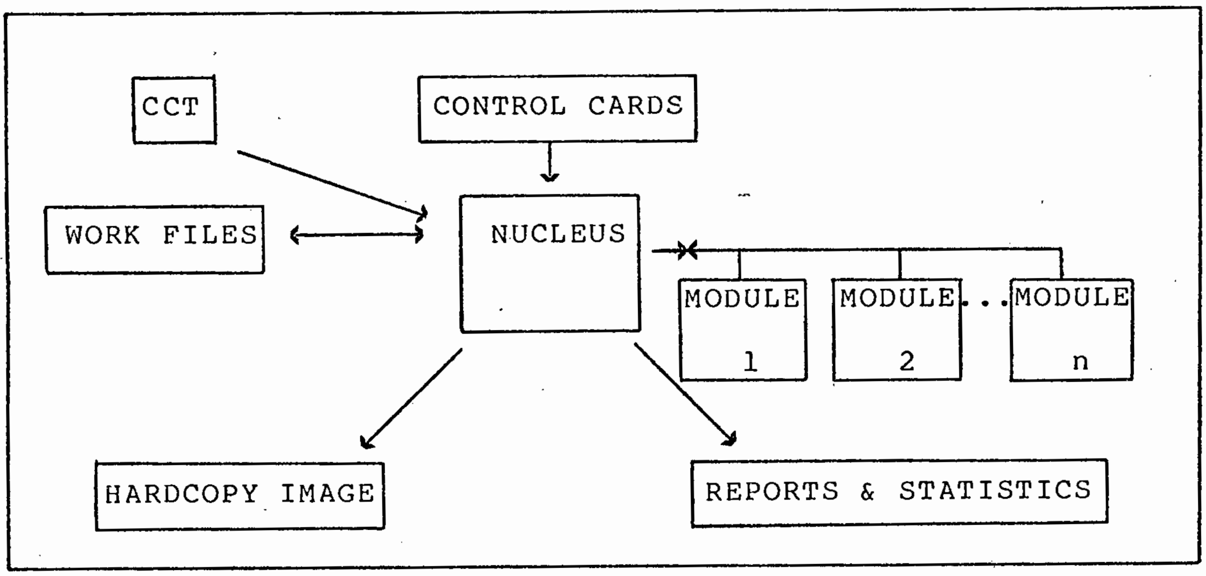
The image processing system used for this project is known as the PIPS system. PIPS is the acronym for Portable Image Processing Suite.

PIPS is a modified translation of the Video Image Communications and Retrieval System (VICAR) of the Jet Propulsion Laboratory, California, USA. Vicar operated on an IBM computer and was translated at the Department of Computer Science, University of Cape Town, during 1977 and 1978, to operate on the university's UNIVAC 1100 computer. At this stage it was known as the Cape Town Image Processing Suite (CATNIPS). At the end of 1978, a copy was taken to the University of Natal (Durban), where it was further modified to operate on their Univac. It then became known as PIPS. In 1982 most of the routines were rewritten into modern Fortran, making the system more versatile and easier to operate. As not all routines are operable on the new system, both systems have been maintained and have become known as

"Old PIPS" and "New PIPS" respectively. Routines from both these systems were used in this project.

The structure of the programme is shown in Fig 3-1. It comprises of a nucleus and a large number of processing modules. The nucleus controls the operation of the programme, by receiving information from the analyst, interpreting it and calling the relevant module to execute the operation. Each module consists of a number of similar tasks or operations. These include Input Tasks for reading the digital data, a CCT, into the system, Output Tasks for instructing the computer as to the type of output required, Processing Tasks, for performing image enhancement, image restoration and information extraction routines, and Statistical Tasks, for performing selected statistical analyses of the digital data. A task is executed by submitting the required control cards to the nucleus. The specific tasks used will be discussed in more detail at a later stage in this report. (Piper and Scogings,1983)

Figure 3-1. A SCHEMATIC VIEW OF THE "PIPS" SUITE.
(Piper & Scogings,1983)



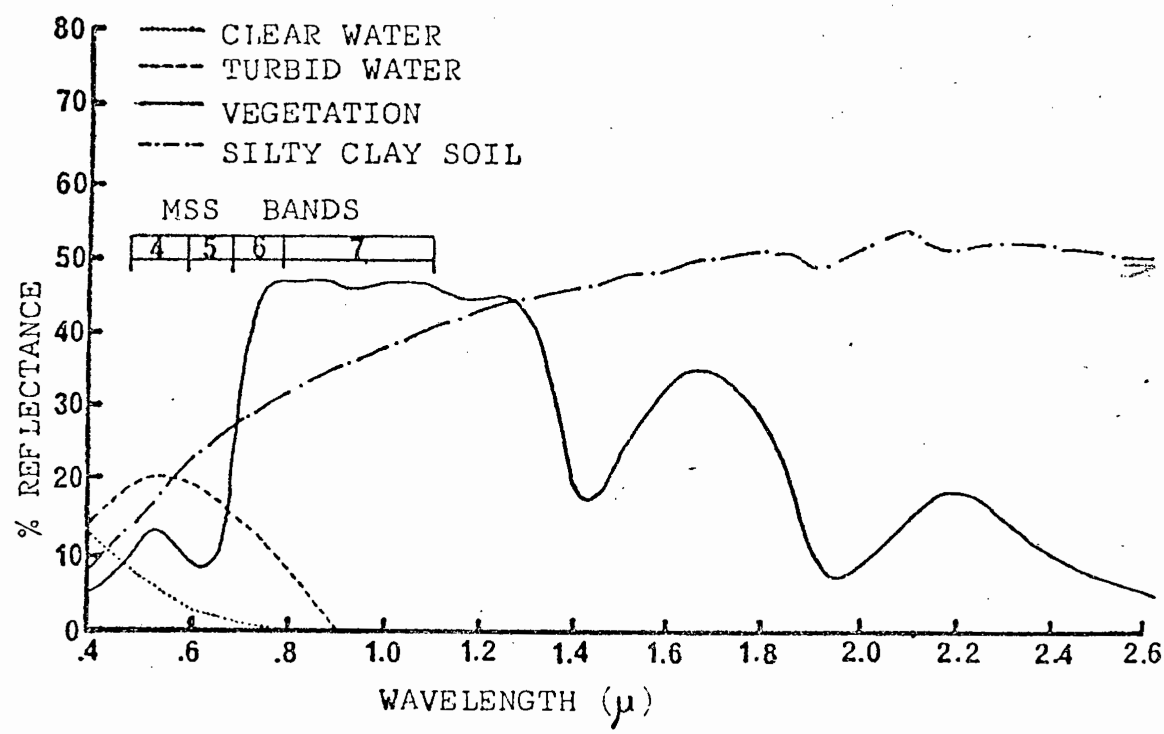
CHAPTER FOUR

4. REMOTE SENSING OF VEGETATION AND THE USE OF RATIOS.

In remote sensing the electromagnetic energy emanating from an object is measured. This measured EME is analysed, studied and then correlated with certain characteristics of the object of interest. The relationship between the amount of EME and the characteristics of interest of the object, is what gives the required information. The spectral signature, the unique amount of EME emanating from an object, which can be used to identify the object or its characteristics, establishes this relationship.

In vegetation studies, information relating to the vegetation is conveyed to the remote sensor by the interactions of EME with the canopy cover and soil. The absorption, reflection and transmission of light by a vegetation canopy, is primarily controlled by the physiology and pigment chemistry of its leaves (Curran,1980). In the reflective infra-red region, the amount of reflectance is dependant on the changes in refractive index between the cell membranes and the cytoplasm as well as between the indiviual cells and air spaces in the mesophyll. Likewise, in the visible region of the spectrum, the pigments in the leaves influence the reflection of EME. The four primary pigments, chlorophyll A, chlorophyll B, beta carotine and xanthophyll all absorb various wavelengths of the visible spectrum. Chlorophyll A absorbs light of wavelengths 0.43 and 0.66 micrometres, while chlorophyll B absorbs light of wavelengths 0.45 and 0.65 micrometres. Beta carotine and xanthophyll both absorb blue and green light. A characteristic reflectance curve for vegetation is given in Fig 4-1 and is contrasted with reflectance curves for soil and water.

<u>Figure 4-1.</u> GENERALIZED REFLECTANCE CURVES FOR THREE LAND COVER TYPES. (Lane,1980)



In attempting to use remote sensing to assess vegetation amount (biomass), the difference between the spectral signatures of the vegetation and the background soil and rock is significant. If their signatures are similar, for example, both light soil and healthy vegetation have a high infra-red reflectance, a poor correlation between reflected infra-red EME and vegetation amount will be obtained. If however, their signatures are different, such as dark soil with a low infra-red reflectance and healthy vegetation with a high infra-red reflectance, the correlation will be good. Other factors which influence these correlations are:

1. The moisture content of the vegetation and soil, as water has a unique spectral signature.
2. The state of the vegetation. Senescent vegetation, for example, has a higher red reflectance owing to the breakdown of pigments in the canopy (Colwell,1974).
3. The angle of irradiation. This influences the size and amount of canopy shadow that is recorded on the image.

4.1. BAND TO BAND RATIOS.

A band to band ratio involves the arithmetic division of the reflectance values of one spectral band by the reflectance values of the same pixel in the second spectral band. This results in a third "band", the values of which are the result of the arithmetic operation.

Band to band ratios are used mainly for two reasons. A ratio has been found to increase the relationship between the spectral values (ratioed values) and the vegetation amount.

It is also useful to use an image resulting from a ratio operation as on such an image, the effects of radiation differences resulting from topography are neutralized.

4.1.1. RATIOS IN VEGETATION ANALYSIS.

Vegetation, in some wavelength bands, for example, in the red portion of the visible spectrum, absorb a large proportion of the electromagnetic energy. This results in a low spectral value in these bands. In other wavelength bands a high spectral value is obtained. If two such bands are ratioed, the resulting value, the difference between the bands, is better related to the vegetation amount than any of the original bands on their own. (Curran,1980) Some of the more common ratios are given in Table 4-1.

It should be noted that the appropriate ratio must be selected to suit the spectral data available. Some of the ratios are designed specifically for LANDSAT data (for example, the Green Vegetation Index), while others are more suited to data having a poisson distribution (for example, the Transformed Vegetation Index is more suited to a poisson distribution than the Vegetation Index). A further point on the use of ratios is that the correlation between vegetation amount and the ratioed spectral value can be adversely influenced by the vigour of the vegetation. Some authors (Curran,1980) suggest that the ratio of a red band to an infra-red band, is more closely related to vegetation productivity than to vegetation amount. This suggestion is based on the fact that during high productivity, much photosynthic activity is occurring. The pigments absorbing the energy for photosynthesis are thus plentiful, absorbing large quantities of red light and only reflecting a little. The red spectral values are thus lower, the more vigorously the vegetation is growing.

Table 4-1. COMMON BAND TO BAND RATIOS FOR VEGETATION AMOUNT (Curran,1980)

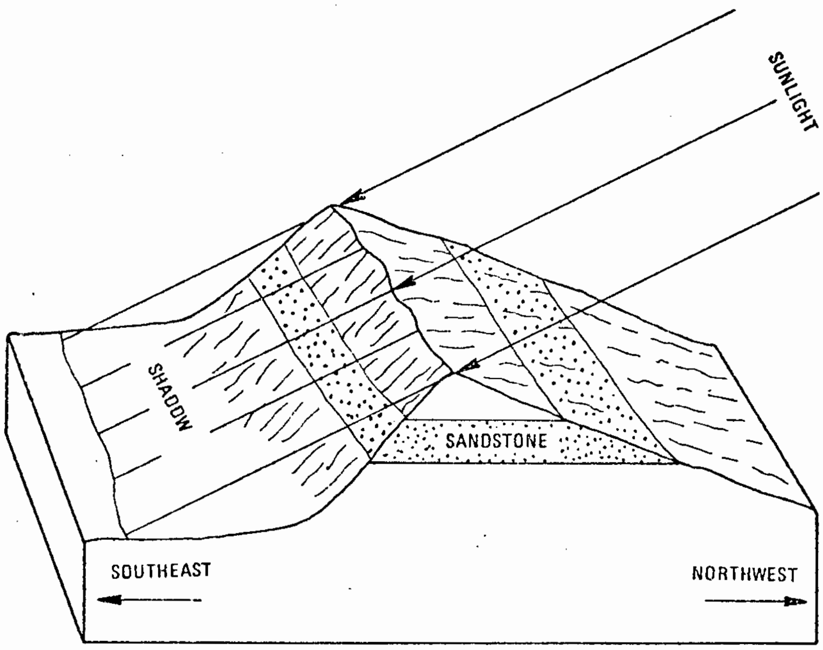
NAME	FORMULA
Simple subtraction	IR-R
Simple division	IR/R
Complex division	$\frac{IR}{R + \text{other wavelengths}}$
Simple multiratio (vegetation index)	$\frac{IR-R}{IR+R}$
Complex multiratio (transformed vegetation index)	$\frac{IR-R}{IR+R} + 0.5$
Green vegetation index (use with LANDSAT MSS bands)	-0.29(G)-0.56(R) +0.60(IR)+0.49(IR)

G = green R = red IR = infra-red

4.1.2. RADIATION DIFFERENCES CAUSED BY TOPOGRAPHY.

As Fig 4-2 shows, ratioing two spectral bands together removes the difference in irradiation, resulting from the topography of the terrain. This implies, theoretically, that in a ratioed band all objects with similar spectral properties should have the same ratio value and topographic effects are removed from the image completely. For vegetation investigations in mountainous terrain, this should be of great assistance. It should however be noted that the ratioing operation reflects the steepness of the spectral reflectivity curve of the two bands, ie. the difference between the spectral values of the two bands. This can result in two dissimilar objects, one with a high albedo or reflective ability, the other with a low albedo, appearing similar on the ratioed image, ie. the differences in albedo, which can be useful in identifying objects is surpressed (Sabins,1978). A further assumption made when bands are ratioed to remove topographic effects, is that the reflectance in all bands will decrease by the same proportion in the shadowed areas. As the amount of light reflected, is proportional to the amount of incoming radiation, this assumption is not true for areas falling into dark shadow. In dark shadowed areas the only source of radiation is diffused (scattered) skylight. As light from different wavelengths is scattered by different amounts, according to Rayleigh's Law, the irradiation of a shadowed area is spectrally different (Fig 4-3). Ratioing is therefore only suitable for removing the radiation differences on areas receiving direct sunlight.

Figure 4-2. REMOVAL OF TOPOGRAPHIC RADIATION DIFFERENCES ON A RATIO IMAGE.(Sabins,1978)

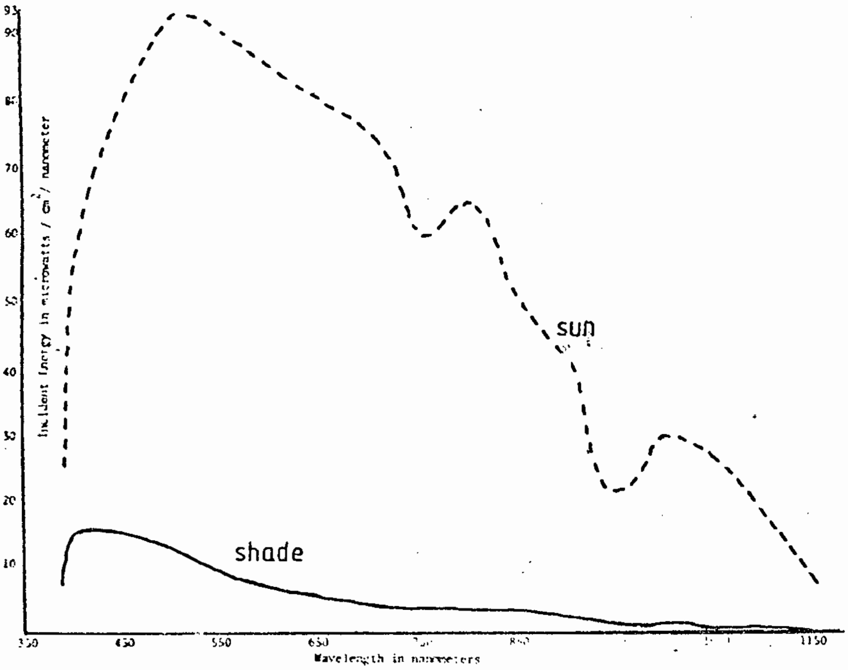


SANDSTONE REFLECTANCE

	BAND 4	BAND 5	RATIO 4/5
Sunlight	28	42	0.66
Shadow	22	34	0.65

Figure 4-3. SPECTRAL DISTRIBUTION OF SUN AND SHADE.

(Yost & Wenderoth, 1969)



CHAPTER FIVE

5. WATER RESOURCE AND FYNBOS MANAGEMENT.

5.1. WATER RESOURCE MANAGEMENT.

South Africa has for many years been concerned about its water resources and the management of its water catchment areas. As long ago as 1934, the Parliament of the Union of South Africa, passed a resolution calling on the government to investigate the drying up of many of the country's rivers and to take steps to ensure the conservation of the country's water resources. This resulted in the appointment of an interdepartmental committee who recommended the need for:

1. A detailed analytical study of the catchment areas of the Union.
2. Legislation for the proclamation of national catchment areas, for the expropriation of land in catchment areas and for the conservation and management of these areas. (Department of Agricultural Technical Services,1961)

These recommendations were implemented by the introduction of new, and the amendment of existing legislation. Acts, such as the Forest and Veld Conservation Act, No 13 of 1941, the Soil Conservation Act, No 45 of 1946, and the Natural Resource Development Act, No 51 of 1947, resulted. A further implementation was that the then Department of Forestry, which had over the years accumulated a lot of non agricultural state owned land for afforestation, was given control of all state land, identified as catchment areas (Ackerman,1976).

In 1952 the report of the Commission of Enquiry into the country's water laws was published. This report again emphasized the concern of the agricultural community for the country's water resources. A resolution by the Soil Conservation Board resulted in the appointment of yet another interdepartmental committee. It was this committee's task to investigate the problems of the conservation of the major catchment areas in the country. In 1961 the "Ross Report" (Ross was chairman of the committee) was released. This was the first attempt at a detailed survey of the country's water catchment areas envisaged twenty seven years ago in 1934 (Department of Agricultural Technical Services, 1961).

The next major step in the conservation of the country's catchment areas was taken in 1970, with the promulgation of the Mountain Catchment Areas Act, No 63 of 1970. The reason for this action was an attempt to centralize the task of the protection of mountain catchment areas. Control was vested in one department, the Department of Forestry (now Department of Environment Affairs). This step, it was hoped, would allow for a co-ordinated conservation action, not apparent before. Previously, control of these areas was vested in a number of different Acts, administered by various State Departments (Rabie,1976) (Fuggle and Rabie,1983). This act empowers the Minister (of Environment Affairs) to declare any area as a Mountain Catchment Area and to issue directives relating to the conservation, use, mangement and control of such land (Republic of South Africa, 1970).

Nine such areas have already been declared in the Western Cape Forest Region alone and the management of these areas is the responsibility of the Directorate of Forestry. As the aim of catchment management is the production of abundant clean water and because of a close relationship between soil, vegetation and water conservation, management uses the manipulation of the vegetation to achieve its goal. A sound knowledge of the vegetation is therefore essential for sound management.

5.2. THE MANAGEMENT OF FYNBOS.

Wicht (1945) states that the indigenous vegetation of the Western Cape Province of South Africa is a most suitable ground cover for the production of water. Fynbos (the local name for this vegetation) has a relatively low basal area, allowing the water to percolate into the coarse sandy soil reservoir with ease, yet the characteristic high crown cover reduces the effects of wind and water erosion. Its ability to quickly recover after fire, covering the exposed mineral soil, adds to its attraction as a catchment cover.

Good (1964) considered the vegetation of this region unique enough to warrant its own floristic kingdom. This kingdom, the South African kingdom, has only one region, the Cape Region. Werger (1978) names this region Capensis.

The uniqueness of the region is characterized by :

1. An exceptionally high species density both in a small area and over the whole region. Taylor (1978) notes that more than 121 species have been found within 100 square metres and that the region contains in excess of 6000 species.
2. A high degree of endemism. There are seven families endemic to this region :Bruniaceae, Geissolomataceae, Grubbiaceae, Penaeaceae, Retziaceae, Roridulaceae and Stilbaceae, as well as numerous genera and species. (Taylor,1978)
3. Capensis is the smallest of the six floral kingdoms described by Good (1964) emphasizing its importance and uniqueness.

In 1979 the "Fynbos Biome Project" was initiated by the Council for Scientific and Industrial Research (CSIR) of South Africa. The Fynbos Biome covers basically the same area as Good's Cape Region and Werger's Capensis. This project was set up in recognition of the scientific and aesthetic importance, and of the economic importance of the water catchment and recreational potential of this ecosystem. Its aim is the co-ordination of research and synthesis of scientific information, relating to this biome. (Day et al,1979)

5.2.1. MOUNTAIN FYNBOS.

Acocks (1953) places the mountainous areas of this region into veld type numbers 69 (macchia) and 70 (false macchia).

Taylor (1978) combines these two types into mountain fynbos. Moll and Bossi (1983) , in an attempt to update Acocks work, found that these types covered a total area of 37310 square kilometres of which seven percent are no longer in a natural state.

As this project is concerned with the extraction of management information from remote sensing data, the following discussion will attempt to outline the type of information that may be of use to the mountain catchment manager. Discussion will be restricted to mountain fynbos.

To date no universally accepted vegetation classification system exists for the fynbos. Inspite of many attempts, (see Moll et al,1983) by various authors to develop a satisfactory classification, much discussion still surrounds this topic. None of the existing classifications have proved entirely satisfactory for management purposes. Taylor (1978) suggests the reasons for this are the complexity of the vegetation and that most of the research effort to date, has been directed towards solving the taxonomic problems of the fynbos. There has also, until recently, been no need for a classification of this vegetation.

Taylor (1978) defines fynbos as having two salient floristic features, the lack of a single species dominance, and/or the conspicuous presence of members of the family Restionaceae. Physiognomically he characterizes fynbos with three elements. These are the proteoid or protea like element, the ericoid or erica like shrubs and the restioid or grass like element.

He divides mountain fynbos into three broad categories. These he calls the Proteoid zone, the Ericoid - Restioid zone and the Hygrophilous fynbos.

5.2.1.1. THE PROTEOID ZONE.

This zone predominates on the foothill plains, lower slopes and plateaus of the mountains. The soils of these areas are coarse grained, shallow, white or grey, Table Mountain Sandstone Sands or deeper more fertile brown or redish loams on granite or shales. The zone is dominated by the tree-like proteoid element of fynbos (1.5 + metres). Species such as Protea neriifolia, Protea laurifolia, Protea nitida and Leucospermum conocarpodendron are common. Protea nitida appears to be replaced by Leucospernum conocarpodendron nearer the coast. Widdringtonia nodiflora appears as a dominant in older veld. Some of these species are seed regenerating species, which require up to 11 to 15 years (Moll et al,1980), before sufficient seed is produced. These species are economically important for commercial flower production. In the past, many of the lower slopes of the mountain have been regularly burnt at short intervals to provide grazing. Many fire belts have been maintained on these lower slopes. This has resulted in severe degradation of this zone and the elimination of the seed regenerating species in many areas.

5.2.1.2. THE ERICOID-RESTIOID ZONE.

This zone is usually found on the upper slopes, ridges, plateaus and summits of the mountains. Soils are shallow, coarse, acid and porous, and are derived from the Table Mountain Sandstones. Shale bands with finer, more fertile, but still shallower soils are not uncommon in this zone. As rainfall increases with altitude and high mountain peaks may receive as much as 5000 millimetres of precipitation per year, this zone is of importance for catchment management. This zone has no tree like element, probably owing to its exposure to high winds. The height of the vegetation in this zone varies between 20 and 150 centimetres. This vegetation type is never, except after a fire, green in colour. It is normally yellowish green, or dun brown in colour with seasonal splashes of yellow, white, pink or mauve, caused by flowering ericas.

The main species found in this zone belong to families like Ericaceae, Penaceae, Rhamnaceae, Rutaceae and Restionaceae. Shrubs from genera such as Leucadendron, Berzelia and Psoralea are also present.

5.2.1.3. HYGROPHILOUS FYNBOS.

This category includes all those communities found on permanently wet or moist sites. River and stream banks, marshes, seepage areas, pans and moist flats are examples.

Taylor (1978) claims that vegetation on these sites, if it were not for fire, would succeed to a non fynbos vegetation, as the summer drought conditions characteristic of the ecosystem are absent. Examples of these communities are the climax kloof forests (remnants or extensions of the Knysna forests, Acocks type 4), the preclimax Brabeium stellatifolium communities, the Berzelia-Osmitoposis communities of drainage lines and seepage areas, the Berzelia-Pseudobaeckia communities of the Kogelberg area and the Restioid communities of seepage areas and pans.

As many of these hygrophilous communities are very localized and small in size, mapping of them is a problem.

Taylor's categories, although useful for management, are very broad. Campbell et al (1981) suggests a more structural classification, based on height, percentage cover and life form (Table 5-1). This classification has not been widely used.

5.3. FIRE IN FYNBOS.

As fire has been and still is a major factor in the fynbos, information relating to the interactions of fire and fynbos are considered of great value to the catchment manager.

Wicht (1945) describes four ways in which fynbos species survive a fire.

1. Most geophytes (eg. Watsonia) regenerate from their underground storage organs. Soil is an extremely efficient insulator, protecting these organs from

the heat damage of a fire.

2. Plants, such as many of the Restionaceae, sprout and regrow from their root stocks, which are also protected from fire by the soil.
3. Some plants, Protea nitida, for example, have a thick insulating bark to protect dormant buds on their stems from the fire.
4. There are many woody plants (eg. Protea laurifolia) that are killed by fire and regenerate from seed.

The seed regenerating type is of special importance to the manager as they can be severely reduced in number by the injudicious use of fire. Many of these plants, especially those requiring seven years and longer to produce a seed supply, are found in Taylor's (1978) Proteoid type. The sprouters are of importance as they recover remarkably quickly after a fire, reaching eighty percent of prefire canopy and basal covers, within two years of a burn (Kruger,1979). This quick recovery assists in reducing erosion, thus promoting the catchment management goal of providing clean, silt free water.

Kruger (1979) describes the successional phases of the fynbos after a burn.

His first phase, the Immediate Post Fire phase lasts for one year. During this time most species regenerate. Within a few weeks, or even days, the sprouters appear, followed by the geophytes, who complete their lifecycle during this phase and lie dormant until the next fire.

The following phase, the Youth phase, lasts up to five years. During this phase the Restoid herbs and sprouters dominate and reach reproductive maturity. The veld becomes flammable at an age of about four years.

Table 5-1. STRUCTURAL FORMATIONS IN THE FYNBOS BIOME.

(Campbell et al,1981)

PROJECTED CANOPY COVER OF THE DOMINANT STRATUM (%) (3)

GROWTH FORM OF THE DOMINANT STRATUM (3)	100-75 interlocking crown	75-50 crowns not interlocking	50-25	25-5	5-0,1
Tall Trees >10 m	Tall Forest	Closed Woodland		Open Woodland	Sparse Woodland
Low Trees <10 m	Low Forest				
Tall Shrubs >2 m	Tall Closed Shrubland (1)	Tall Mid-dense Shrubland	Tall Open Shrubland	Tall Sparse Shrubland	
Mid-high Shrubs 1-2 m	Mid-high Closed Shrubland	Mid-high Mid-dense Shrubland	Mid-high Open Shrubland	Mid-high Sparse Shrubland	
Low Shrubs 25-100 cm	Low Closed Shrubland	Low Mid-dense Shrubland	Low Open Shrubland	Low Sparse Shrubland	
Dwarf Shrubs <25 cm	Dwarf Closed Shrubland	Dwarf Mid-dense Shrubland	Dwarf Open Shrubland	Dwarf Sparse Shrubland	(4)
Shrubs and Graminoids codominant (5)	Closed Graminoid Shrubland (2)	Mid-dense Graminoid Shrubland	Open Graminoid Shrubland	Sparse Graminoid Shrubland	
Graminoids >1,0 m	Tall Closed Herbland (2)	Tall Mid-dense Herbland	Tall Open Herbland	Tall Sparse Herbland	
Graminoids <1,0 m	Closed Herbland	Mid-dense Herbland	Open Herbland	Sparse Herbland	

(1) When greater sophistication is required the terms Small-leaved, Large-leaved, Succulent, Proteoid and Ericoid can be appended to Shrubland (eg Low Open Small-leaved Shrubland).

(2) The term Graminoid can be replaced by Restioid, Grassy or Cyperoid, depending on the dominant graminoid. Similarly Herbland can be replaced by Restioland, Grassland or Sedgeland.

(3) When one wishes to refer to strata other than the dominant stratum, one can use the same terminology for canopy cover and height but the suffix 'land' will be dropped, and the terms Overstorey or Understorey can be used if necessary. Some examples are as follows: Closed Grassland with a Tall Sparse Shrub Overstorey (some Protea Pseudo-Savanna in the eastern mountains); Mid-high Mid-dense Shrubland with an Open Restioid Understorey; Tall Closed Proteoid Shrubland with a Low Mid-dense Shrub Understorey (many of the Protea communities).

(4) When one wishes to refer to low-cover shrubs or graminoids (less than five per cent) then one should use 'Very Sparse' or, if the components are emergents, then 'Emergent' should be used. For example, P. laurifolia fynbos is often Low Mid-dense Shrubland with Tall Emergent Proteoids.

(5) The Graminoid Shrubland formations should be given a height class description as for the Shrubland formations, eg Low Mid-dense Grassy Shrubland.

The Transitional phase, lasting up to ten years, comes next. All species have reached reproductive age by this time and the taller shrubs start to emerge above the canopy.

From ten to thirty years, the tall shrubs attain maximum height and reproductive activity. The smaller shrubs (ericas), having completed their lifecycle, start to die and litter accumulates. This is the Mature phase.

The final phase, the Senescent phase, follows from thirty years onwards. During this phase many more of the seed regenerating species die, the canopy opens up slightly and limited germination occurs. Litter accumulation accelerates. On suitable moist, fertile sites, forest species may start to appear.

A map of the spatial distribution of these phases is also of considerable use to the catchment manager.

Moll et al (1980) in summarizing graphically (Fig 5-1) data collected by Kruger, shows the regenerative phases of fynbos in specific groups. These groups closely reflect Taylor's (1978) classification of the fynbos into a Proteoid zone and an Ericoid-Restiod zone.

Furthermore, van der Zel and Kruger (1975) found that for a high rainfall catchment (annual rainfall 2 000 millimetres), stream flow diminished by 19.1 millimetre for every year the veld aged. The implication of this for the catchment manager is that by reducing the average age of his catchment vegetation by burning it, he can increase the runoff or visa versa. A knowledge of the age structure of a catchment vegetation will therefore be of value to him.

In fire management generally, the following vegetation parameters are valuable indicators of fire behaviour.

1. Vegetation density.
2. Fuel quantity, ie. the biomass per unit area.
3. Fuel quality on the bases of specific area, where the greater the surface area of the fuel, the greater the rate of burn and intensity of the fire.
4. Oil content of the fuel (inflammability).
5. Moisture content of fuel (reduces inflammability).

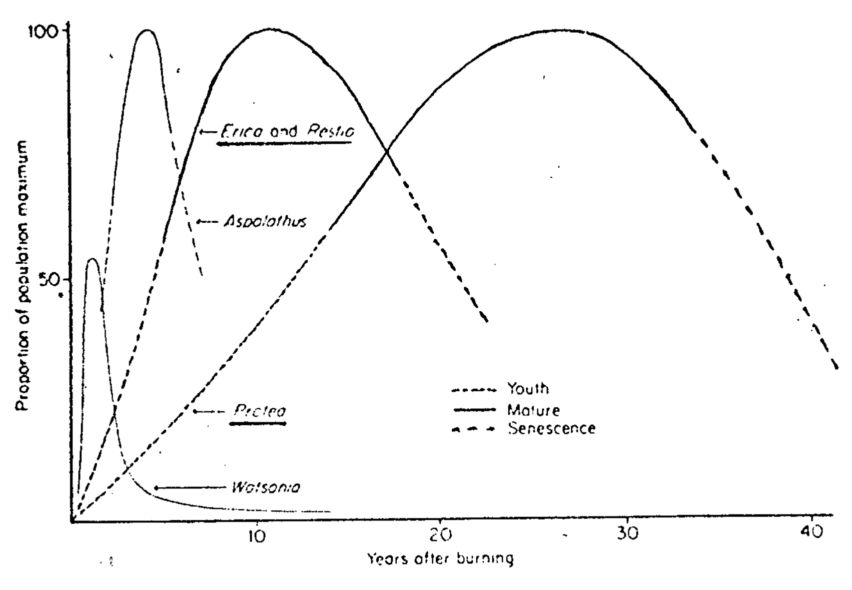
Based on the above, it is therefore the task of the Remote Sensor to try to establish the relationships between the electromagnetic energy emanating from the vegetation and the following vegetation characteristics.

1. Floristic, physiological and structural groupings within the vegetation.
2. Age of the veld (in years).
3. State of maturity of the veld (degree of senescence).
4. Biomass or fuel quantity (biomass per unit area).
5. Vegetation density (ease of penetrability for management).
6. Fineness of the vegetation on the bases of specific area.
7. Oil content of the vegetation.
8. Moisture content of the vegetation.

As topography (slope and aspect) also affect fire behaviour and vegetation characteristics, correlation between these and EME are also regarded as useful information for the catchment manager.

Owing to the limitations of the image processing system used, the date of the digital image, financial and time constraints, not all these relationships could be thoroughly investigated in this project.

<u>Figure 5-1.</u> REGENERATION, FLOWERING AND GROWTH OF FYNBOS AFTER FIRE. (Moll et al,1980)



CHAPTER SIX

6. METHOD.

In trying to prove the acceptability of the hypothesis set out for this project, the investigations were guided by the following four objectives:

1. Assess the significance of the problem of topographic shadow on information extraction procedures.
2. Investigate ways of overcoming this problem.
3. Investigate the existence of relationships between the spectral data and selected useful management information.
4. Develop a basic methodology for compiling thematic maps of the fynbos, from remote sensed digital information, at a scale suitable for mountain catchment management.
5. Produce a thematic map of the study area, illustrating the results of the above investigations.

6.1. THE IMAGE.

The first step in any Remote Sensing project is the selection of the appropriate imagery.

For this project a LANDSAT 2 MSS Scene (ID 22228 - 07483) was selected for analysis. It covers the area from the Cape Peninsula in the west to Cape Agulhas in the east and reaches north as far as Paarl. The central latitude of the scene is 34 degrees 24 minutes south, while the central longitude is 19 degrees east. The World Reference Number for the scene is, path number 187 and row number 84. The data was captured at around 07h50 GMT (09h50 local time) on the 27 February 1981. The image comprises information for four wavelength bands. These are labelled bands 4, 5, 6 and 7 (Table 6-1).

Table 6-1. LANDSAT MSS WAVELENGTH BANDS. (Taranik,1978)

BAND NUMBER	WAVELENGTH WIDTH
4 (green)	0.5 to 0.6 micrometres
5 (red)	0.6 to 0.7 micrometres
6 (infra-red)	0.7 to 0.8 micrometres
7 (infra-red)	0.8 to 1.1 micrometres

For each pixel, covering a ground area of 56 metres x 81 metres, there are four digital values, each with a value of between 0 and 255 (eight bit value), proportional to the amount of reflectance in the represented wavelength band.

The image is available in digital format on a computer compatible tape, and can thus be used in a digital image processing system.

This particular image was selected for the following reasons:

1. It was available as a CCT on loan from the Fynbos Biome Project and did therefore not have to be purchased.

2. It is an image of sound quality and is largely cloud free.

3. It is a summer image with the sun azimuth (70 degrees) and sun altitude (39 degrees) near to their maximums, so minimizing the topographic shadows on the image.

4. As much of the fynbos vegetation is dormant during summer and vegetation vigour is therefore near zero, the ratioing of wavelength bands would not be adversely influenced by vegetation vigour (see section 4.1.1).

5. Ground Control Points referenced to the South African National Co-ordinate System were available, for geometrically correcting this image, thus saving many hours of research time. These data were available from the Fynbos Biome Project.

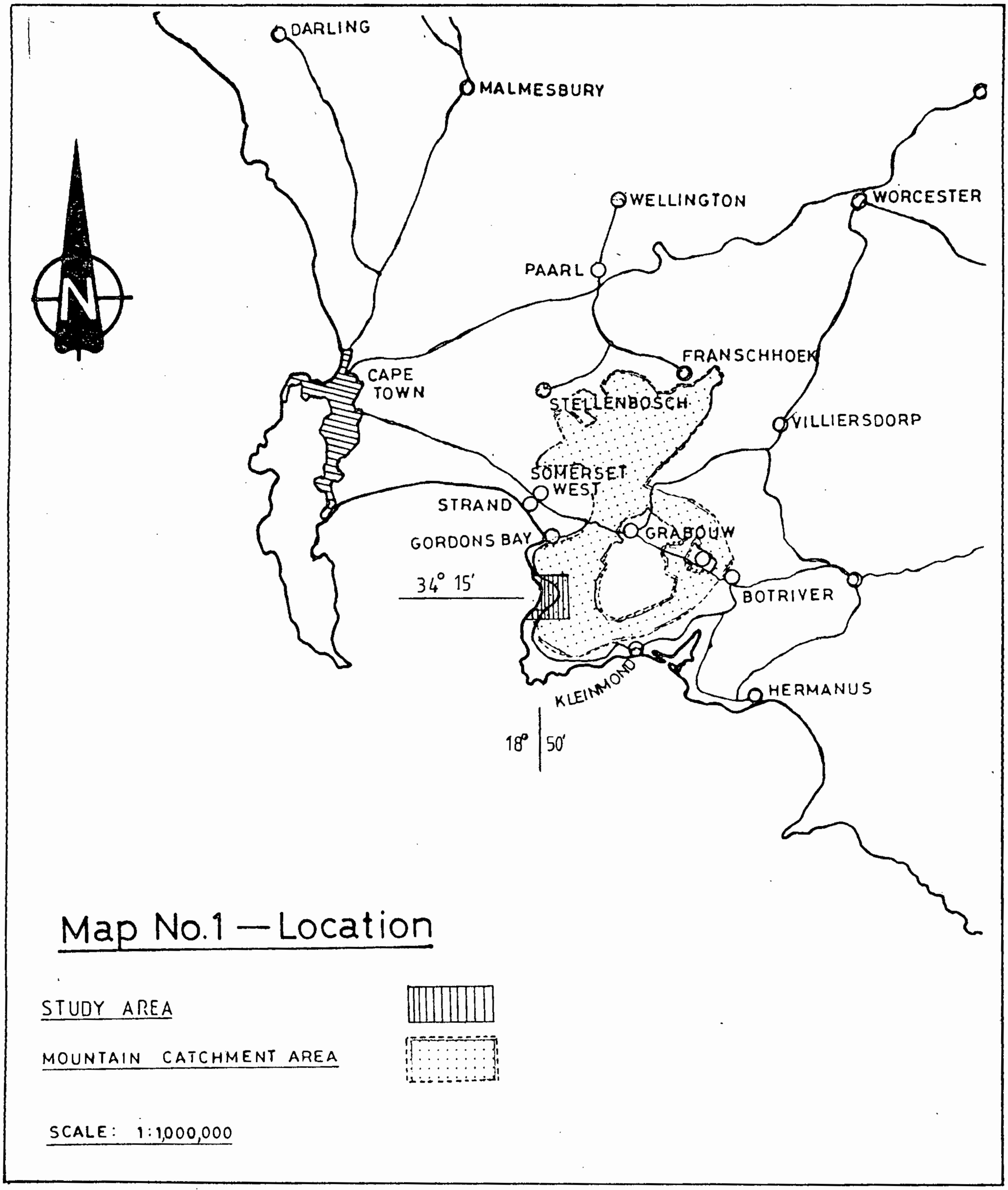
6. A geometrically corrected, edge enhanced 1:250 000 black and white photographic print of band 7 of this image was also available on loan from the Fynbos Biome Project. This product was useful for general orientation and project planning.

7. The image contained large areas of topographic shadow falling onto fynbos vegetation.

As processing of the whole image was considered too great a task for the scope of this project, a 10 kilometre x 10 kilometre sub-image was selected for processing.

6.2. THE STUDY AREA.

Map 1 LOCATION OF STUDY AREA.



6.2.1. THE LOCATION.

This sub-image, the study site, is located on the eastern side of False Bay and falls partly within the Kogelberg State Forest and partly within the Cape Town City Council Steenbras Forest Reserve. (Map 1) The area lies approximately on latitude 34 degrees 15 minutes south and longitude 18 degrees 53 minutes east. It is readily accessible by road and footpath.

6.2.2. DESCRIPTION.

6.2.2.1. TOPOGRAPHY.

On the western side, the area rises gradually from sea level over the Kogelberg basin (300 metres), and then steeply, almost precipitously up onto Kogel Peak (1280 metres). It then drops steeply to the west into the valleys of the tributary streams of the Palmiet river and finally down into the Palmiet river valley itself. It is bounded in the south by the short steep Rooi els river and in the north by the Steenbras river watershed. This gives the area a variable, rugged topography, so typical of the mountain catchment areas of the Fynbos Biome. The topography causes large areas of shadow to occur on the imagery.

6.2.2.2. GEOLOGY AND SOILS.

Two major geological formations (de Villiers et al,1964) are present in the area.The Kogelberg basin on the western side of the area includes rocks of the old Klipheuwel System. This formation comprises of layers of sub-greywacke, fine shales, conglomerates and quartzitic rock.

In this area, it is light brown in colour, but has been covered over by the light grey or white sandy soils of Table Mountain Series origin.

The rest of the area is covered by the Table Mountain Series (TMS). This formation supports most of the Fynbos Biome and is thus the typical geological formation on which mountain fynbos grows. It comprises quartzitic sandstone rock with layers of shale exposed in places. These shale layers form the characteristic shale bands of these mountains. The shales are also brownish in colour, but the sandstones are light grey or white.

The soils of the area are generally nutrient poor, coarse, acidic, sandy soils, originating from the TMS sandstones. In places on the shale bands, where the soils are richer in nutrients and finer in texture, the vegetation is markedly more vigorous. This can be seen on the shale band on the south side of Groenkop.

On the steeper mountain slopes the soils are shallow, consisting mainly of exposed rock and lithosols. The Mispah form is common here.

In the valleys and flatter areas, where alluvial and colluvial accumulations occur, the soils have deep, coarse, acidic and bleached sandy horizons.The typical formation on these sites is the Fernwood form.

The Champagne form, a formation black in colour and rich in humus, can be found in some marshy and wet seepage areas.

6.2.2.3. THE VEGETATION.

Except for the exotic vegetation around the Kogel Bay recreation resort and Rooi els village, and a narrow strip of coastal vegetation along the western edge of the area, the whole area is covered with Mountain fynbos (see section 5.1).

All three of Taylor's (1978) categories and all five of Kruger's (1979) successional phases are represented in the area.

The vegetation on the western side (sea side) of the study site has been subjected to the injudicious use of fire for many years.This has caused changes in structure of the vegetation, resulting in a varied mosaic of vegetation structures along the fire boundaries. On the rest of the site, sound management has been applied for a long time. Here the veld is in a pristine condition and is representative of the true diversity of mountain fynbos.

6.3. REASONS FOR STUDY SITE CHOICE.

This area was chosen as a study site for the following reasons:

1. The image revealed a large shadowed area, on the western foot of Kogel Peak as well as many lesser shadowed areas. The shadowed areas were required to satisfy one of the objectives of this project, ie. to investigate the effect of shadow on the interpretation of the imagery.
2. The site falls within a recognized research area of the Directorate of Forestry.
3. The area is located reasonably close to the project's research centre, the University of Cape Town.
4. It is readily accessible by road and is traversed by a number of footpaths.
5. The topography and vegetation are representative of mountain fynbos catchment areas.
6. Ground reference data, in the form of maps and large scale (1 : 20 000) aerial photographs are available for this area.
7. Suitable digital imagery covering this area is available.

6.4. THE MAPPING SCALE.

Suitable scales for general management maps for catchment management, in the area under discussion, are at scales of

1:50 000 or 1:100 000. These scales are considered by Jarman et al (1981), to be suitable for semi-detailed and reconnaissance scale of vegetation mapping. A 1:50 000 scale is the scale presently recommended for management maps of mountain catchment areas by the Directorate of Forestry. Jarman et al (1981) also points out that the absolute maximum scale of mapping, possible from LANDSAT MSS imagery, is at 1:10 000. This conclusion is based on investigations, where mapping was done on reasonably flat terrain and topographical effects were minimal.

At a scale of 1:25 000, one pixel is represented by approximately one print character on the computer print-outs. As the only available hard copy products obtainable for this project, are line printed print-outs, and because of the severe topography of the study area, this was regarded as the maximum possible scale to use as a working scale. For the final map products, halving or quartering the scale to 1:50 000 or 1:100 000 would produce the desired management maps.

6.5. GROUND REFERENCE DATA.

The following ground reference data was used in this project.

1. Selected 1:20 000 colour aerial photographs of Job 794 flown in 1977.
2. A 1:250 000 black and white geometrically corrected, edge enhanced image of band 7 of the LANDSAT scene used.

3. A 1:25 000 photographic enlargement of the South Africa 1:50 000 map series of the area. A transparent overlay at the same scale, depicting the contours, rivers and roads, was produced from the photographic enlargement, and used as a reference map on the classified print-outs.
4. Field measurements obtained during the course of the project.
5. 35 millimetre colour transparencies (colour slides) of the vegetation of the area.
6. A 1:1 000 000 black and white photographic print of band 5 of the image used.

6.6. ASSESSMENT OF THE AMOUNT OF SHADOW.

In order to establish the relevant importance of the effect of shadow on the imagery, the first step in this project, was to quantify the proportion of shadow area in the Hottentots Holland Catchment Area. This proportion can probabily be used as an indication of the amount of shadow that can be expected in mountainous terrain in the Western Cape.

As an indication only was desired, an exact measurement was not considered necessary, and the following method was used.

The Hottentots Holland Mountain Catchment Area, the mountainous areas between Betty's Bay in the south and Franschhoek, in the north, was regarded as a typical Western

Cape Mountain Catchment Area, and an estimate of the amount of shadow present on the image was estimated. A transparent plastic film was placed on top of the 1 : 250 000 black and white band 7 photographic print of the image, and the approximate boundaries of the catchment area were sketched onto the film. A 0.5 centimetre x 0.5 centimetre dot matrix was then drawn onto the film and the number of dots falling on shadow areas were counted and ratioed with the total number of dots falling within the catchment. To determine the shadow boundaries in a non subjective way, band 7, the band with the longest wavelength, was used. On this band, the shadows will appear the blackest of all four bands, owing to Rayleighs scattering being a minimum. The shadowed areas were identified as those areas which were not water bodies, but which were the colours of the two darkest of the sixteen grey levels of the print. Pixel values of less than 32 would have been assigned to these grey levels. A ten times magnifying glass was used to check on doubtful dots. Only shadowed areas larger than 1,5 millimetres x 1.5 millimetres (25 hectares) were registered. The results are discussed in the following chapters.

6.7. DIGITAL IMAGE PROCESSING.

The digital image processing system used for this project was the PIPS system (see section 3.2) available on the University of Cape Town's SPERRY (UNIVAC) 1100 computer.

The task "intape" was used to load a portion of the CCT onto four disc files. Each of the four disc files contained information for one of the four wavelength bands. The initial sub-image copied from the CCT started at data line number 450 and data row number 810. A block of 500 by 800 pixels was copied.

During initial exercises, while still gaining familiarity with the system, an error in the "intape" routine was detected. It was found that "intape" was not reading the CCT data correctly into the disc files, in that the first two columns of data relating to band 6, the first four of band 5 and the first 6 columns of band 4 of the specified sub-image, were not being copied over onto the disc files.

The task "copy" was used to correct this error. Data from bands 5, 6 and 7 were copied over onto new files, so that the first column of each of these bands were registered to the first column of band 4, ie. the first six columns from band 7, the first four columns from band 6 and the first two columns from band 5, were not copied into the new files.

This was followed by the use of the "affine" task to alter the scale and geometrically correct the image, so that the 1:25 000 ground reference map could be superimposed, accurately, onto the image print-outs. The affine transformations are described in section 3.1.1 of this report. The image used in this project was previously used by Bossi (1983), who also performed a geometric correction on it. The required ground reference points and their pixel and SA Co-ordinate System co-ordinates were therefore available and were used in this project. The seven points supplied to the routine are given in Table 6-2. The specified scale was 1:25 000 and the latitude required by the programme was given as 34 degrees 15 minutes south, the centre latitude of the study area. The output image resulting from the transformation, is not rectangular, but skewed, to allow the lines of longitude and latitude to run vertically and horizontally across the image. On the untransformed image, because of the nine degree inclination of the satellite's orbit (section 2.1), these lines run at an angle across the imagery.

The task "copy" was again used to copy out a true rectangular image from the transformed image, so eliminating it's unaesthetical skewed appearance. The copied image was 138 x 191 pixels. This image formed the study area described above. The task "disply" was used to produce line printer grey scale print-outs of the images of each of the four bands.

Table 6-2. GROUND REFERENCE POINTS FOR GEOMETRIC CORRECTION.

POINT	GEODETIC CO-ORDINATES		PIXEL CO-ORDINATES	
	Y (LO 31)	X	LINE	SAMPLE
1	52450.	733750.	140	510
2	63550.	767850.	590	340
3	46270.	803020.	1030	590
4	-26720.	833190.	1400	1680
5	-58280.	850700.	1610	2140
6	-85030.	778760.	710	2580
7	-97537.	853270.	1640	2740

6.7.1. TRAINING AREAS AND THE UNSUPERVISED APPROACH.

Owing to the natural diversity of fynbos and the aim of this project, to investigate the existence of relationships between the spectral data and useful management information, an unsupervised approach of spectral classification was decided upon. The unsupervised approach groups the spectral values of an image into classes with similar spectral responses (see section 3.1.3.2). These classes were then correlated with the collected ground reference data, with the aim of detecting any relationship between the classes spectral characteristics and information, that may be useful to management. With a supervised approach, the analyst is required to first select the information he requires for management, and then seeks to find the spectral characteristics of the desired information. It was felt that adopting the supervised approach would lead to useful correlations being missed.

Twelve training areas of 400 pixels each were selected from the image and these were knitted together to form a sub-image of their own. The task "concat" was used for this operation. This sub-image, represents 18 percent (4800 pixels) of the total study area.

The following criteria were used in the selection of the twelve training areas.

1. The training areas were to cover the whole spectrum of topographic conditions.
2. They should cover the whole range of possible

vegetation types, found in the area.

3. Each training area should contain more than one distinct information class.
4. At least two training areas should contain a large area of deep shadow, for evaluating this aspect of the project.
5. The training areas combined, should be spectrally representative of the whole study area.
6. In the selection of training areas, distinct features such as, patches of indigenous forest, were considered for inclusion in the training areas. It was hoped that these features would be spectrally distinct from the surrounding vegetation, so giving clear reference points to aid interpretation of the classified image.

After scrutiny of the relevant 1:20 000 colour aerial photographs, the selected training areas were sketched onto the line printed print-out of band 7 of the image. Each training area was 20 x 20 pixels in size. The co-ordinates of each training area were noted and supplied to the "concat" routine, for processing. The combined sub-image of all twelve training areas, one for each of the four bands, resulted.

The training areas were also plotted on the 1:25 000 map and annotated onto the relevant 1:20 000 colour aerial photographs.

The task "histgm" was used to generate histograms of the data of each band, one for the whole image and one for the combined training areas. A study of these histograms, revealed that the training areas were representative of the whole image. The only noteworthy discrepancy in the histograms, being the bias of selecting training areas on land and not favouring the sea to the same extent. This was considered acceptable, as the project is concerned with terrestrial vegetation only. For the purpose of investigating the existence of relationships between the spectral characteristics of the data and useful management information, only the concatenated sub-images were processed further. In the discussion that follows the word "image" will, unless otherwise indicated, refer to the concatenated sub-image of the twelve training areas. The location of these training areas are given on Map 2.

6.7.2. SHADOW MASKING.

One of the aims of this project was to discover whether the data in deep shadowed areas (areas receiving no direct sun irradiation), was diverse enough to enable the clustering algorithms to operate on them, producing a meaningful classification. A means was therefore sought by which the shadow areas could be separated from the rest of the image and processed separately.

A comparison of the line printer print-outs with the 1:250 000 black and white photographic print of band 7, revealed that most of the shadow areas on the image were represented in band 7, by the two grey scales of the line printer, having the lowest values. There are sixteen grey scales on the print-outs, representing a range of 256 values. Each grey scale therefore represents sixteen values. The two lowest grey scales would represent the values 0 to 31. With the aid of the task "number", the actual pixel values of band 7, for a few selected areas, were printed out. This revealed that the shadowed areas generally had a band 7 pixel value of less than 35. An examination of the histogram of band 7 reveals the bimodal nature of the data. Bands 5 and 6 also show this tendency. As water bodies have a very low albedo, it can be assumed that the mode containing the lower pixel values contains the pixels representing both the water and shadow areas.

It was therefore decided to create two image masks, so that these two data modes could be separated into different data sets. The shadow/water mode could then be processed separately from the rest of the image. This would take into account the spectral irradiation conditions of dark shadow areas as discussed in section 4.1.2, in that vegetation regions, with different radiation sources, would be classified separately.

As water bodies are easily identifiable, using other reference data, the inclusion of the spectral data of water areas, which is similar to dark shadow spectral data, in the shadow data set, was of little significance. In the production of the final map product, these water bodies would be identified and mapped as such.

The task "strech" was used to generate two binary images, where in one image a zero replaced all the band 7 values of 36 and above, while all the values below 36, were replaced by a value of one. In the second image, all values above 35 were replaced by ones and values of 35 and below, were replaced by zeros. With the aid of the "arithm" task, either one of these images could be multiplied with any other image of the same area and the result would be an image with either the water/shadow elements or the non water/shadow elements removed. These images could then be processed separately.

6.7.3. FEATURE EXTRACTION.

All feature extraction was guided by the first two goals set for this project (section 6).

With the aid of the "arithm" task and the "ratio" task, from old Pips, a number of ratioed images were generated. The decision to use ratioing as a means of feature extraction in this project, was motivated by three factors. Firstly, an aim of the project, is to investigate the effects of topography on the imagery. By ratioing, the differences in irradiation conditions are reduced (see section 4.1.2). Secondly, ratioing is useful for extracting certain vegetation characteristics (see section 4.1.1). Thirdly, ratioing has not been very thoroughly investigated as a means of feature extraction in natural vegetation.

The ratios selected for evaluation in this project are listed in Table 6-3. It should be noted that the arithmetical ability of the Pips system is limited and restricted the choice of ratios to a degree.

Pips is only able to operate with a sixteen bit value (0 to 255), thus any ratio resulting in values beyond this range, are truncated to fall within this range, often rendering the data worthless. Furthermore, certain data sets were not accepted by the task "itclus". These images are indicated in Table 6-3.

A number of these ratioed images were selected and multiplied by the binary images, resulting in three images each for the selected ratio, a water/shadow image, a water/shadow free image and a total image.

All the generated images were classified separately with the aid of the "itclus" task, based on the isodata technique of Ball and Hall (1976) (see section 3.1.3.2). Although the "itclus" task can classify a combination of up to nineteen versions (bands) of an image at one time, it was decided to classify only one version at a time. This greatly simplified the detection of relationships between the spectral data and management information.

A classified image was printed out on the line printer, using the task "mapcls", in each case. The print-outs were evaluated against the collected field measurements, with the aim of detecting any relationships between the spectral values and useful management information.

Based on these results, two images were selected and used to train the classifier, and a thematic map of the study area was generated. Here again, only two images were used to simplify the evaluation of the product. The selected images were chosen because of a strong relationship between their spectral data and a useful management information source. The task "ictlus" was used to generate the class signatures. The task "edsig" was used to select the signatures of those classes, identified as information classes and the task "maxlik" (the maximum likelihood classifier), was used to classify the whole study area. The task "predom" was used to remove noise from the classified image, so making it aesthetically more acceptable. The task "mapcls" was used to generate a line printer print-out of the thematic map, from which the final map was prepared. Details of the tasks mentioned above, can be found in the Pips Manual (O'Donoghue et al,1983).

6.8. THE COLLECTION OF FIELD MEASUREMENTS.

Based on the experience of Lane (1980), who collected detailed and precise field measurements, and experienced some difficulty in correlating these data with the large pixel size of the LANDSAT image, a more coarse approach of field measurement was adopted. The main aim of collecting field measurements was to obtain data, which could be used to investigate the existence of relationships between the spectral data and management information. It was therefore decided to collect data which would, firstly, be able to be interpreted into useful management information and secondly, could be used to explain unexpected results on the classified images. A method of transsect sampling was devised in which one or more transsects were laid out in each of the twelve training areas. The length of these transsects varied between 375 metres and 1000 metres. The selected length depended on the diversity of vegetation within the training area. Where the vegetation consisted of small areas of distinct vegetation with clear ecotones, short transsects were preferred. Longer ones were laid out in areas where the vegetation was more uniform and the ecotones not distinct. Twenty transsects were laid out in total of which two complete ones, and part of a third, were located in deep shadowed areas. More intense sampling in the shadowed areas would have been desirable, but it was found that most of the deep shadowed areas, fell on precipitous, inaccessible areas.

The location of the transsects were determined by the diversity of the vegetation in each training area. Transsects were placed so as to cross as many ecotones per training area, as possible, either as one long transsect or as a number of shorter ones. The location and length of the transsects are shown on Map 2.

At 25 metre intervals along the transsect (measured with the aid of a 2.5 metre ranging rod) a data sheet was completed.

Table 6-3. RATIOS USED FOR EVALUATION.

LANDSAT BANDS	SHADOW ONLY	SHADOW FREE	TOTAL IMAGE
4	no	no	yes
5	no	no	yes
6	no	no	yes
7	no	no	no ?
7-5	yes	yes	no ?
6-5	no	no	yes
7/5	yes	yes	yes
6/5	no	yes	no
$\frac{7}{4+5}$	no	yes	no
$\frac{6}{4+5}$	no	yes	no
$\frac{7-5}{7+5}$	yes	yes	yes
$\frac{6-5}{6+5}$	no	yes	no
GVI*	no	yes	no
SBI*	no	yes	no
YVI*	no	no	no

*GVI=-0.29(band 4)+0.49(band 7)+0.6(band 6)-0.56(band 5)

*SBI= 0.43(band 4)+0.63(band 5)+0.25(band 7)-0.59(band 6)

*YVI= 0.82(band 4)+0.53(band 5)-0.05(band 6)+0.19(band 7)

? = not accepted by "itclus".

6.8.1. THE FIELD SHEET.

Appendix 1 contains an example of the field sheet. The sheet is divided into ten data fields. It was designed in a way that allows the data to be summarized in the compartments of the score column for easy computerization.

The form was printed on green paper to reduce eye strain, which would result from using white paper in the sun.

The first field (LOCATION) contains: the date on which the form was completed, the training area number (1 to 12) in which the transsect is located, the number of the transsect in that training area, and the sample point number on the transsect. The direction refers to the direction of the transsect from the first sample point. This information is of assistance in maintaining a straight line in the field and also for identifying the starting point of the transsect from the end point. A five figure code summarizing the data was placed in the first score compartment. The first two figures give the training area number, the third was the transsect number and the last two, the sample point number. The date and direction were not required for analysis and were thus not included.

The second field (REFLECTIVE INDEX) contains the aspect of the slope on which the sample points were located and the angle of that slope. Both these values were measured in degrees, the slope with a Suunto clinometer and the aspect with a prismatic compass. The score compartment contains two three figure values. The first is the aspect in radians and the second is the slope, also in radians. The degrees were converted to radians as the programme used in the data analysis required angles to be in radians. Slope and aspect were included as they were required as input into the formula for calculating the amount of radiation reaching the sample point. This is useful for evaluating the effect of topography on the imagery. Slope and aspect are also useful parameters of fire behaviour and are thus useful for obtaining management information.

The third field (SHADOW) was included to label those sample points falling into deep shadow. During the data analysis, this label was used to separate out the shadow data. The decision as to whether a point was located in the shadow or not, was based on the elevation and azimuth of the sun at the time of image capture. The elevation of the sun at that time was 39 degrees (0.679 rad) and the azimuth was 70 degrees (1.226 rad). This data was obtained from the image label on the CCT. If any topography, located to the east north east of the sample point, had an elevation angle of greater than 40 degrees above the horizontal, the point was labelled as falling into deep shadow. A "1" in the score compartment indicated this, a "2" indicated a sun irradiated point.

The fourth field (BACKGROUND COLOUR) was included to evaluate the influence the rock and soil had on the classifications. A crude four figure scale was used to label the background colour of the sample point. A figure of 1 for white, 2 for grey, 3 for brown and 4 for black, was placed in the score compartment.

The fifth field (VELD CONDITION) contains a measure of the veld's vigour. As the age and condition of the veld are useful management parameters, a relationship between these measurements and spectral values would be very useful. Veld condition was judged on a scale of 0 to 10, using age and general appearance as decision criteria. Indigenous forest was placed on the scale at value 10. General fynbos was placed at a value of approximately half its age. Veld of age ten years, for example, would have a condition value of 5. The score compartment contained a two digit figure, the veld condition value.

The sixth field (VELD TYPES) contains a list of the veld types occuring in the study area. The absence of a sound management orientated veld type classification system for mountain fynbos (see section 5.2.1) necessitated the creation of a coarse system for use in this project. This system is based on systems described in the Hawequas Mountain Catchment Area management plan (Dir of Forestry,1980) and the Groot Winterhoek Mountain Catchment Area policy memorandum (Dept of Forestry,1979). Table 6-4 summarizes this system. With the data from the field, the generation of a computerized veld type map, with LANDSAT spectral data as input, was planned. The assumption that was tested was that the described veld types are spectrally different and thus classifiable on a digital image. The number of the veld type was scored in the score compartment.

Table 6-4. VELD TYPES.

VELD TYPE	HEIGHT	DESCRIPTION
1. Low Restio	0.5 m	Found on shallow soils, acts as soil cover, does not burn easily.
2. Tall Restio	2-3 m	Often on wet sites, acts as a water filter and sediment trap, used by the flower industry, recovers quickly after a burn.
3. Restio-Shrub	1.5 m	Most common type, has aesthetical value and limited potential for flower harvest and grazing. Burns from age four years.
4. River Shrub	5 m	A specialized habitat, can succeed to forest, burns under severe conditions.
5. Forest	15 m	Specialized habitat of scientific interest, acts as water filter, will not burn, but ecotone is damaged by fire.
6. Shrub	5 m	Ecologically important, being the only fynbos type containing tree elements. Utilized for flower harvesting, burns readily and is damaged by frequent fires.
7. Medium Shrub	1 m	Often indicates disturbed sites, succeeds to some other type. Acts as ground cover, burns very easily, leaving site exposed.
8. Aliens		Undesirable species in natural vegetation.
9. Other		Tar road, gravel road, quarries, etc.

The seventh field (LEAF SURFACE) was used to record the geometry of the leaves, covering the sample point. It was assumed that the large flat leaves of the indigenous forest trees and tree proteas would reflect light differently from those fynbos species with small ericoid leaves. The stem leaves of the restoid element would reflect characteristically as well. If this assumption were true, a relationship would exist between the leaf geometry and the spectral data of the image. A score of zero in the score compartment would indicate a broad flat leaf. A restoid stem would score a 10, while a 5 would be scored by a pure ericoid leaf or a 50-50 mixture of broad leaves and restoid stems.

The eighth field (VEGETATION COLOUR) was included, to evaluate the influence of vegetation colour on the imagery. Although not directly useful to management , it was suspected that it may influence the classifications to some degree and was thus included. Colour is scored on a scale of 1 to 5, 1 being dark green, 2 light green, 3 grey, 4 light brown and 5 brown.

The ninth field (PERCENTAGE COVER) was used to record the percentage canopy cover at the sample point. The percentage of dead canopy cover and the percentage of live canopy cover were roughly estimated by visual inspection. The estimation of background cover was used as a control. The score compartment contained three values, the percentage live, dead and total cover.

The tenth field (HEIGHT) was reserved for mean vegetation height around the sample point. Five to ten heights were measured with the aid of a 2.5 metre ranging rod, within a five to ten metre distance from the sample point. The average height of all those recorded, was placed in the score compartment. This measurement was in centimetres. The number of height measurements were dependant on the uniformity of the height of the vegetation around the point.

Both cover and height are useful management parameters and in combination were used to give a biomass index.

The transsects were plotted in the field onto the 1:20 000 colour aerial photographs and transferred in the laboratory, onto the 1:25 000 map. At a scale of 1:25 000, the distance between points on the transsect is one millimetre. By overlaying the 1:25 000 map onto the classified image print-outs, the location of the transsects could be plotted onto the classified image. As an aid to plotting the transsects on the concatenated training area image, a cardboard template was constructed with the beginning and end points of transsects marked by pin holes. By placing the template over the classified image and running a pin through the holes, the start and end points of each transsect, were marked on the image. These were joined by a straight line, indicating the positions of the transsects.

6.9. DATA ANALYSIS.

The main aim of the data analysis was to obtain an indication of the existence of relationships between the image spectral values and useful management information. To achieve this, the field data was combined with the spectral data in the following way. For each point on the twenty transsects, the field measurements were recorded against the spectral class into which the point fell on the classified image. This was done by noting on the field sheet, the classes from the various classified images into which the point fell. A pair of dividers set to a gap of one millimetre was used to pace along the transsects plotted on the classified images, and the class number of each point was noted.

The field measurements and spectral classes for each point, were then placed on a computer disc file and further analysed with the aid of the BMDP statistical package (Dixon ed,1981). The routine BMDP7D was used to group the field measurements with their corresponding spectral classes and to generate a histogram for each spectral class, showing the distribution of the selected field measurements within that class. It also computed the mean and standard deviation of the field measurements in each class and printed the minimum and maximum values of each group as well as the number (n) of measurements in each group. It computes the analysis of variance (ANOVA) of the means of the classes and prints the ANOVA table.

Although the analysis of variance table was requested for all the field parameters, it was meaningless for a number of them, owing to the nature of their measurements. Veld type, vegetation colour and background colour were recorded on a nominal scale. These parameters were therefore evaluated only on the basis of a visual interpretation of the histogram, drawn by the programme. None of these histograms showed a clear enough trend to warrant further analysis for establishing the degree of correlation.

The computational ability of this programme was used to compute three further field parameters, from the raw field data. A biomass index, a fire index and an reflective index were created.

6.9.1. REFLECTIVE INDEX.

A reflective index was considered desirable for evaluating the effectiveness of the various band ratios in neutralizing the differences in reflectance, caused by topography.

It is assumed that the solar radiation reaching the vegetation canopy, fynbos in this case, is reflected equally in all directions (isotropically). It can therefore be stated that the EME reflected by the vegetation canopy, is directly proportional to the amount of radiation incident of the canopy.

A study of Kondratyev's (1969) formula for direct solar radiation of a slope :

$$S_{sl} = S_m[\cos H_\odot \sin\alpha \cos(A-a) + \sin H_\odot \cos\alpha]$$

where S_m = Solar Radiation incident on the surface, perpendicular to the sun's rays.

S_{sl} = Direct sun radiation of a slope.

$H_\odot$ = Height of the sun.

α = Angle of the slope.

A = Azimuth of the sun.

a = Aspect of the slope.

shows that the amount of radiation incident on an area, with a given slope and aspect, lying in the direct solar beam, is the solar beam radiation reduced by the factor $[\cos H_\odot \sin\alpha \cos(A-a) + \sin H_\odot \cos\alpha]$.

This factor can therefore be regarded as an index of the reflected radiation, because of the incoming radiation being directly proportional to the reflected radiation. The solar beam radiation is regarded as constant for the whole study area and the altitude and azimuth of the sun, is also a constant, for the duration of image capture. The topography's changing slope and aspect are therefore the only elements that affect the index and thus reveals the effect of topography on the reflected radiation. The reflected radiation is what is quantitatively monitored on the imagery, and this is what is being studied. The index used was therefore

$$\text{REFLECTIVE INDEX} = [\cos H_{\odot} \sin\alpha \cos(A-a) + \sin H_{\odot} \cos\alpha]$$

6.9.2. BIOMASS INDEX.

A biomass index was considered desirable as biomass is a useful management parameter, which cannot be easily measured in the field. By combining the field measurements of height and percentage cover, a useful indication of biomass can be obtained for evaluating the relationship of biomass to spectral information. The formula used was Biomass Index = Height x Percentage Cover Total.

6.9.3. FIRE INDEX.

Fire is the most important management factor in the fynbos catchment areas. Any information, relating to the rate of spread of a fire, or its intensity, is useful to management. As the degree of slope and biomass both influence the rate of burn and aspect can be correlated with moisture and temperature of the vegetation, both affecting the intensity of the burn, combining these parameters into a fire index was considered.

The degree of slope and aspect was indexed according to Table 6-5 and the formula Fire index = Biomass Index x Slope Index x Aspect Index, was used to generate this index. The slope index was based on the fact that the flatter the slope, the slower the fire burns, providing the fire burns uphill. The aspect index was based on the fact that the northern aspects are hotter and drier than the southern aspects and a fire therefore burns more fiercely on a northern aspect, than on a southern one, providing both aspects have the same biomass or fuel load.

This index is designed to account for fires burning up a slope only, and therefore cognicance needs to be taken of the direction of the burn, whether it is uphill or downhill, before this index can be applied.

These indexes were analysed by the BMDP programme with the rest of the field measurements. Based on the output from this programme, the mean spectral value of a spectral class, obtained from the spectral signature of the class, could be plotted graphically against the mean measurement for the selected field parameter of the points falling into that spectral class. With the aid of a Hewlett- Packard HP 32E calculator, a set of correlation coefficients and regression equations were calculated. Only those parameters that showed significant differences between their means in each class, based on the results of an ANOVA, and showed a clear trend on the graph, were considered for regression and correlation analysis. Where it was considered applicable, a log transformation was performed on the spectral class means, to improve the linear relationship. These results are given in the next chapter.

Table 6-5. SLOPE AND ASPECT INDEX.

SLOPE INDEX		ASPECT INDEX	
SLOPE IN RADIANS	SLOPE INDEX	ASPECT IN RADIANS	ASPECT INDEX
0-0.17	1	0-0.52	4
0.17-0.44	2	0.52-1.57	3
0.44-0.87	3	1.57-2.62	2
0.87-1.57	4	2.62-3.67	1
		3.67-4.71	2
		4.71-5.76	3
		5.76-6.28	4

CHAPTER SEVEN

7. RESULTS AND DISCUSSION.

7.1. ASSESSMENT OF THE AMOUNT OF SHADOW.

The transparency placed over the 1:250 000 black and white print, (see section 6.6) contained 591 dots falling within the catchment boundaries. The mean number of dots (of three counts) falling in shadow areas was 85. This gives an approximate shadowed area in the Hottentots Holland Catchment Area of 17 percent. The true value of the amount of shadow is greater than this figure, as small areas (areas less than about 20 hectare) of shadow could not be reliably identified at this scale.

A visual study of the print revealed that most of the shadowed areas were located on steep, often precipitous slopes, where vegetation could reliably be expected to be minimal. To map all shadowed areas as "cliff face vegetation", would thus be one possible solution to overcome the effect of shadow on the imagery. Although this method can be expected to produce results acceptable for general management purposes, a more reliable method was sought.

7.2. RESULTS OF DATA ANALYSIS.

The four single bands, bands 4,5,6 and 7 and sixteen ratioed combinations were examined for useful correlations of spectral values with management parameters. The correlation co-efficients obtained are given in the tables that follow.

An examination of the graphs and their corresponding histograms revealed that some of the points on some of the graphs of height, biomass index, fire index and veld condition, were, when plotted on the graphs, positioned well away from a position that would place them on the expected curvi-linear line through the rest of the points. It was found that these outliers could be brought more in line by removing from the field data base, those height measurements, greater than five metres, which caused these points to be disturbed (see Graph No.13 & 14).

Most of these outliers were caused by exceptionally tall height measurements in classes that generally contained much lower height measurements. The suggested explanation for this phenomenon is based on the occurrence of the small patches of tall forests in the study area. A pixel covers a ground area of 56 metres x 81 metres, but field measurements were taken at points 25 metres apart. Therefore, where a pixel was located over an area covering fynbos and forest, the two or three field measurements relating to that pixel, covered the fynbos and forest as well. If the spectral value of the pixel was influenced more by fynbos, it would very likely be classified into a fynbos class during the clustering procedure. As the forest patches are usually small narrow strips of vegetation, they can seldom be expected to dominate a pixel. In the BMDP data analysis, the field data of the forests, which included many height measurements in excess of five metres, would then be included with the rest of the fynbos field measurements for that class, resulting in their mean heights being distorted, so causing the point to be an outlier.

This phenomenon was eliminated where possible, by examining the graphs and histograms of height for all images. Where the histograms, from which the height distribution of the spectral class could be seen, explained the unexpected position of a point on the graph, those data points, where a height of more than five metres was measured, were removed from the data base, for analysis of that image. Five metres was an arbitrary assigned value, to differentiate between fynbos and tall forest.

In all cases where the removal of heights above five metres was done, the standard deviation of the means of the field parameters were decreased and the correlation co-efficients improved. This procedure was used on a number of images, including:

GVI, as explained in section 7.2.15

(6-5)÷(6+5) no shadow, as explained in section 7.2.14

7÷4+5 no shadow, as explained in section 7.2.10

6÷5 no shadow, as explained in section 7.2.8

(7-5)÷(7+5) shadow only, as explained in section 7.2.11.1

6÷4+5 no shadow, as explained in section 7.2.9

6-5, as explained in section 7.2.5

7÷5, as explained in section 7.2.7

7÷5 no shadow, as explained in section 7.2.7.3

Each examined image is discussed in detail below and the significant regression equations are given.

A selection of graphs of the spectral values plotted against the field parameters are given for some of the analysed images. Only 24 of the approximately 120 graphs are given in this report. The illustrated graphs have been selected for their explanatory value, or for showing the strong correlation of the selected field parameter with the ratioed image's spectral values.

7.2.1. BAND 4.

The clustering operation performed on band 4, resulted in three classes being distinguished. From the graphs, only three field parameters appeared to correlate well with the spectral measurements. Slope, aspect and reflective index gave correlation co-efficients of 0.99, 0.99 and 0.98 respectively. The regression equations were:

slope = 0.008(band 4) - 0.002

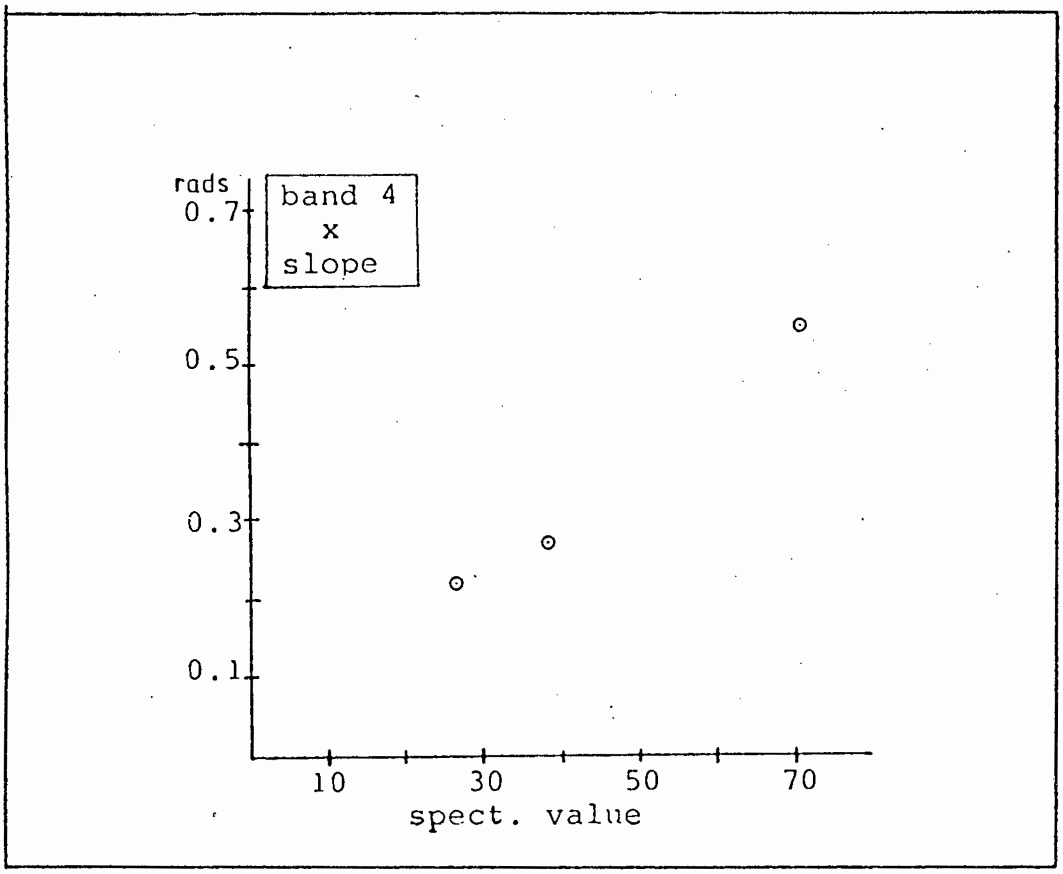
aspect = -0.07(band 4) + 5

reflective index = 0.47 log(band 4) - 0.07

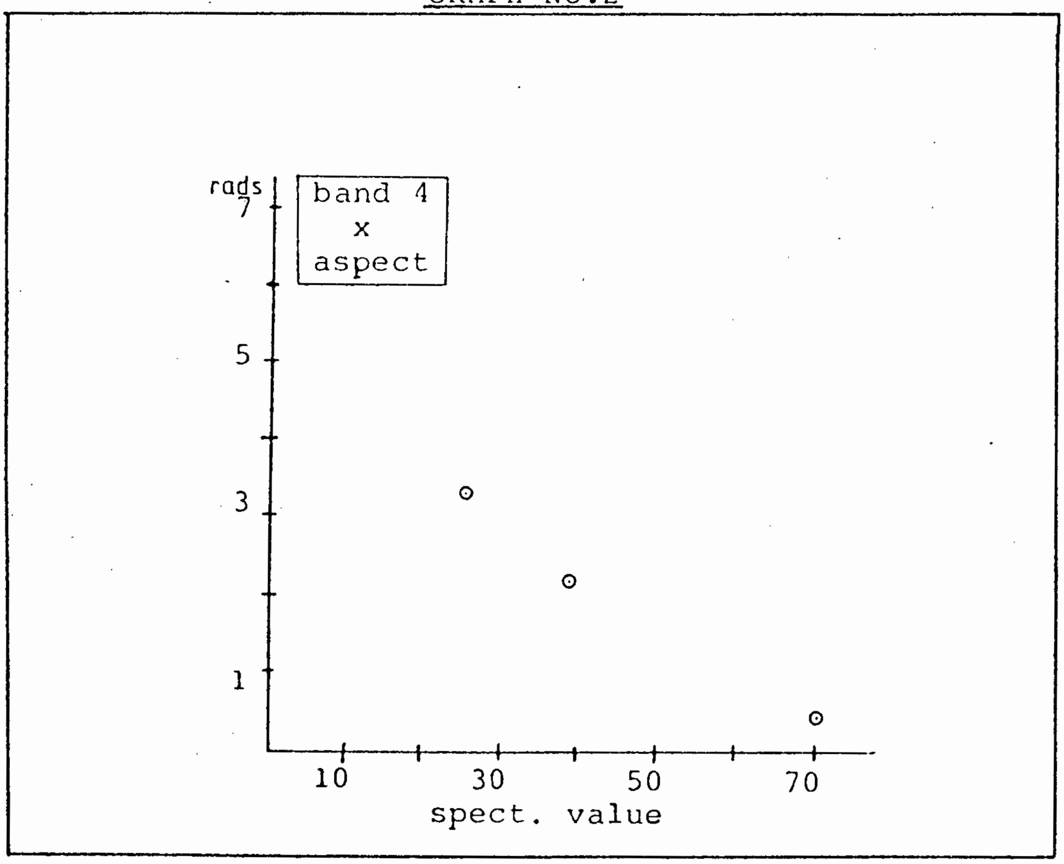
(band 4 = spectral value of band 4 in the above equations). These regression equations and the correlation co-efficients were calculated from three values. Graph No.1 & 2 illustrate slope and aspect.

This band gave the strongest relationship with slope and reflective index, of all the twenty images studied. This strong correlation may result from the use of only three points in the calculations, as there is no reliable way of estimating the confidence of the co-efficient with so few points.

GRAPH NO.1



GRAPH NO.2



Based on these results, the inclusion of band 4, as input into the production of a thematic map, will be most significant if the management parameter, fire index, is being sought. The strong correlation of slope and aspect with the spectral information motivates this suggestion.

A study of the histogram of vegetation colour, revealed some degree of correlation between vegetation colour and the spectral classes. It was however, not possible to establish any measure of correlation, because of the arbitrary scale of colour measurement.

7.2.2. BAND 5.

In contrast with band 4, band 5 reveals strong correlations with height, percentage cover, veld condition (age), biomass index, fire index and leaf surface. A correlation co-efficient of 0.80 significant only at a 90 percent level, was obtained for reflective index as well.

Nine classes were generated by the clustering programme (itclus). Classes 8 and 9, were excluded from all the regression analyses. Class 5 was excluded from all, except height, percentage cover and biomass index. From visual comparison of the line printer print-out, with the aerial photographs, it appeared that classes 8 and 9 were not vegetation classes and were included in the data, as a result of an error in plotting the transsects onto the line printer print-out. These transects appeared to have been plotted on the line printer print-out, 25 to 50 metres to the east of their actual starting point, placing their starting points on the tar road. This caused the field measurements to be coupled with spectral data not related to the field measurements. Class 9 contained only two data and class 8 only one. Their exclusion was therefore not expected to significantly affect the results. Class 5 was identified from aerial photographs as white sand, so that percentage cover, height and biomass could be inferred as zero. These values were plotted against the spectral mean of class 5 on the graph and included in the calculations of regression equations and correlation co-efficients for these parameters.

With this band again, an indication of a correlation with vegetation colour can be obtained from the histogram. This is however not well defined and was therefore not parameterically evaluated.

The usefulness of band 5 appears to be its information content of vegetation parameters. Its strong correlation with leaf surface appears to be particularly useful, if a vegetation classification system can be developed, based on leaf form. This band's inclusion as input into the production of the thematic map of any vegetation management parameter would be appropriate.

The significant regression equations are given in Table 7-1.

Table 7-1. REGRESSION EQUATIONS FOR BAND 5.

Height	= -182 log(band 5)+ 376	n = 7 r =-0.82*
% Cover Total	= -0.88(band 5)+ 106.8	n = 7 r =-0.98**
% Cover Live	= -0.74(band 5)+ 87.0	n = 7 r =-0.98**
% Cover Dead	= -0.20(band 5)+ 21.9	n = 7 r =-0.85*
Biomass Index	= -182.4 log(band 5)+ 370	n = 7 r =-0.90**
Veld Condition	= -0.09(band 5)- 6.50	n = 6 r =-0.96**
Leaf Surface	= 0.05(band 5)+ 4.30	n = 6 r = 0.99**
Fire Index	= -16.7(band 5)+ 935.0	n = 6 r =-0.93**

(band 5) = spectral value of Band 5.

** = 99% significance level

* = 95% significance level

n = number of points in data set

r = correlation co-efficient

7.2.3. BAND 6.

The only significant correlation obtained from band 6 was with aspect. The regression equation is:
aspect = -0.05(spectral value band 6)+5.60. The correlation co-efficient was -0.83, significant at the 99% level.

This correlation was obtained from 9 classes. Class 10 was ignored, as it was obviously an outlier. From the aerial photographs, class 10 appears to be predominately exposed white sand, with a strong reflectance across the whole spectrum. It can therefore be expected that the effect of aspect will be masked by the whiteness of the sand. Had the pixels assigned to class 10 been covered with vegetation, they would probably have been assigned to classes based on their aspect and the outlier would not have occurred.

7.2.4. BAND 7.

The data of band 7 was not accepted by the task "itclus" and further analysis of this band had therefore to be abandoned.

7.2.5. IMAGE 6-5.

The task "arithm" was used to subtract the values of band 5 from those of band 6. The resultant image had 668 pixel values out of the range 0 to 255. These were truncated to zero and had the effect that most of the shadowed areas were given a zero pixel value. This caused class 2 to become an outlier in the data set of leaf surface. The probable explanation for this outlier, can be attributed to the following cause. Normally, the narrower and smaller the leaf, the lower the image's spectral value. In the shadowed areas, however, the image's spectral values are also very low, or were truncated to zero for being out of range. This resulted in broad leaf vegetation, falling in shadowed areas, being placed in spectral classes with low spectral values. This in turn, caused the average of the leaf surface index for class 2, the class with the lowest spectral value, to have an abnormal mean leaf surface index.

In calculating the correlation co-efficient and regression equation for this data set, class 2 was excluded and only the other four classes were used.

The significant regression equations are given in Table 7-2.

Table 7-2. REGRESSION EQUATIONS FOR IMAGE 6-5.

Height	= 1.41 (image 6-5) + 80.85	n = 5	r = 0.92*
% Cover Total	= 0.77 (image 6-5) + 69.31	n = 5	r = 0.83
% Cover Live	= 0.73 (image 6-5) + 55.55	n = 5	r = 0.81
Biomass Index	= 2.50 (image 6-5) + 9.12	n = 5	r = 0.94*
Leaf Surface	=-0.05 (image 6-5) + 7.02	n = 4	r =-0.85
Aspect	=-0,07 (image 6-5) - 4.37	n = 5	r =-0.94*
Reflective Index	= 0.01 (image 6-5) + 0.46	n = 5	r = 0.82

(image 6-5) = spectral value of Image 6-5.
* = 95% significance level.
n = number of points in data set.
r = correlation co-efficient

This image gives a reliable correlation for aspect and height. Biomass index is also strongly correlated, because of the strong correlation with height.

From the histograms of veld types, vegetation colour and background colour, only vegetation colour showed signs of any relationship with the spectral data. This was however, not quantifiable owing to the nature of the vegetation colour measurements.

7.2.6. IMAGE 7-5.

This image was obtained by using the task "arithm" to multiply band 7 values by two and to subtract band 5 values from the product, after dividing them by two: image = [2 x band 7 - 0.5 x band 5]. These arithmetical operations were done in order to keep the resultant values within the eight bit range (0 - 255).

The resultant image was multiplied by the water/shadow only mask and the water and shadow free mask (see section 6.7.2). These three images, the complete 7-5 image, the shadow free 7-5 image and the shadow only 7-5 image, were classified separately with the aid of the task "itclus". The complete 7-5 image data was not accepted by this task and further analysis was therefore not possible.

The analysis of variance tables for all the field parameters of the shadow only image, revealed that there was no significant difference between the means of the field measurements falling into each class. No further analysis was therefore done on this image either.

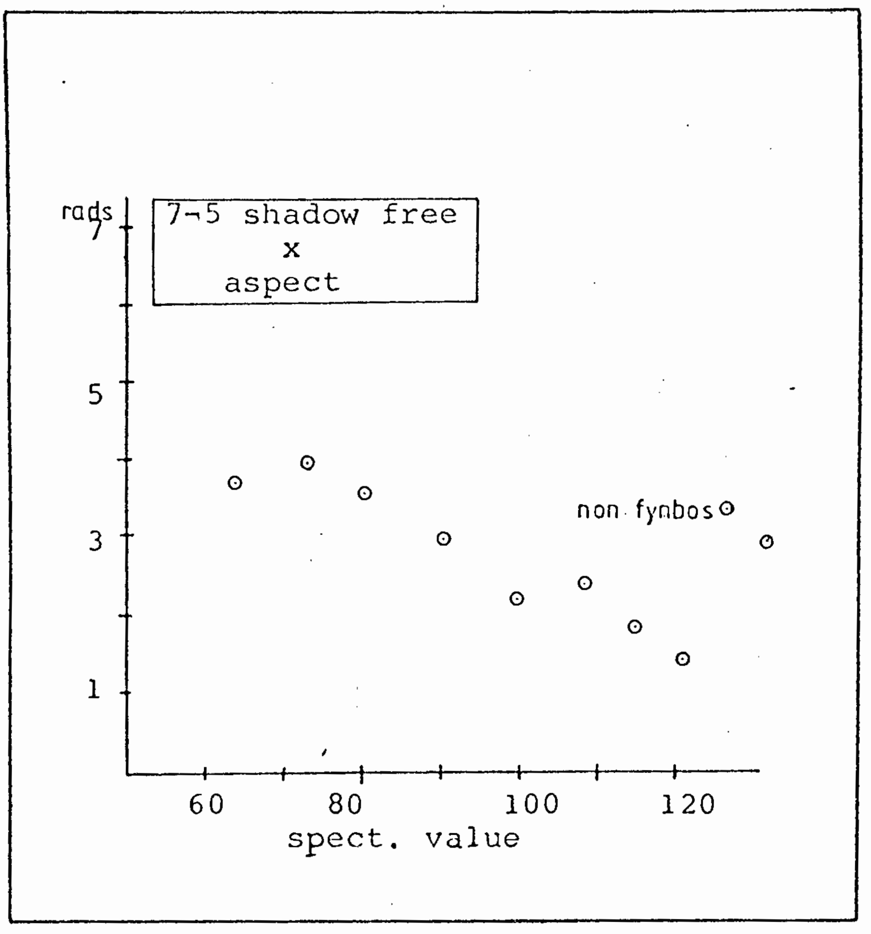
The water/shadow free image (7-5 shadow free) gave the best results. The significant regression equations and correlation co-efficients are summarized in Table 7-3. Eleven classes were generated by the programme. Class two contained all the shadow area and was excluded from the analysis. Class ten and eleven appear to be influenced by the patches of indigenous forest as they contained, besides the typical fynbos field measurements, the indigenous forest patch measurements as well. They were therefore not pure fynbos classes and showed as outliers on the graphs of aspect, reflective index, height, biomass index and fire index (see Graph No.3).

The fact that aspect was influenced by the tall forests can possibly be explained by the location of the forests in deep kloofs as well as by their height. As aspect was measured at ground level in the kloofs, and the sensor was sensing the flat top of the forest canopy, the two measurements cannot be expected to correlate. The height of the forest canopy (20 metres) masks the aspects of the steep kloof banks. In fynbos, the height of the vegetation is low enough to model the ground surface aspect and this masking effect does not occur. In those images where the data points falling into forest areas were removed from the correlation analysis, this anomaly did not occur.

Classes ten and eleven were therefore ignored in the correlation and regression analysis and only eight points (n=8 in table) were used to obtain the regression equations and correlation co-efficients for these data sets.

A study of the histograms of veld types, vegetation colour and background colour, revealed that only veld type and vegetation colour showed evidence of a relationship between the pixel values of the image and the field parameters.

GRAPH NO.3



rads
7
5
3
1
7-5 shadow free
x
aspect
non fynbos
60
80
100
120
spect. value

Here again, it was not possible to quantify this.

Table 7-3. REGRESSION EQUATIONS FOR IMAGE 7-5 SHADOW FREE.

Height	= 1.27 (7-5 shadow free)+ 20.6	n=8 r= 0.52
% Cover Total	= 0.42 (7-5 shadow free)+ 41.67	n=10 r= 0.77**
% Cover Live	= 0.30 (7-5 shadow free)+ 40.30	n=10 r= 0.75*
Biomass Index	= 0.29 (7-5 shadow free)+ 58.5	n=8 r= 0.68*
Fire Index	= 5.25 (7-5 shadow free)- 15.8	n=8 r= 0.43
Aspect	=-0.05 (7-5 shadow free)+ 7.2	n=8 r= 0.96**
Reflective Index	= 0.002(7-5 shadow free)+ 0.42	n=8 r= 0.95**

(7-5 shadow free) = spectral value of image 7-5 shadow free.

** = 99% significance level

* = 95% significance level

7.2.7. IMAGE 7÷5.

The task "ratio" from old Pips was used to create this image. This task performed an arctan function on the result of the division of band 5 into band 7. The arctan function causes the data of the two bands to be linearly related and to maintain a value of between 0 and 255. This image was also multiplied by the shadow/water only, and shadow/water free masks, resulting in three images, a total image (ratio 7÷5), a shadow/water only image (7÷5 shadow), and an image containing no water or shadow (7÷5 no shadow). Each image was classified separately. The significant results of the correlation and regression analysis are given in Table 7-4, 7-5 and 7-6 respectively.

7.2.7.1. RATIO 7÷5

The ratio 7÷5 gave twenty classes. Numbers 18, 17 and 5 contained no field parameters. A comparison with the colour aerial photographs, revealed that class 17 and 5 appeared to be water, while class 18 appeared to be white sand. Furthermore, classes 1, 3, 9, 11, 13, 14, 15, and 16 were identified as classes falling mainly into shadowed areas. The field parameter "shadow" was used to establish this.

Table 7-4. REGRESSION EQUATIONS FOR RATIO 7÷5.

Height	= -2.33(ratio 7÷5) + 318.6	n=11 r=-0.91**
%Cover Total	= -0.67(ratio 7÷5) + 142.67	n=10 r=-0.94**
%Cover Live	= -0.53(ratio 7÷5) + 112.11	n=10 r=-0.91**
%Cover Dead	= -0.16(ratio 7÷5) + 290	n=10 r=-0.84**
Veld Condition	= -0.07(ratio 7÷5) + 9,17	n=10 r=-0.86**
Leaf Surface	= 0.05(ratio 7÷5) + 1.50	n=10 r= 0.82**
Biomass Index	= -2.50(ratio 7÷5) + 325	n=10 r=-0.93**
Fire Index	= -9.09(ratio 7÷5) + 1190,91	n=10 r=-0.88**
Aspect	= 0.03(ratio 7÷5) + 0.70	n=17 r= 0.83**
Reflective index	= 0.002(ratio 7÷5)+ 0.77	n=10 r=-0.75*

(ratio 7÷5) = spectral value of ratio 7÷5.

** = 99% significance level

* = 95% significance level

From the graphic plots (see Graph No.4,5 & 6) of the class means, against the various field parameters, it was found that all vegetation classes with a spectral mean value of 130 and lower, were classes falling within areas receiving direct sun radiation. The graphs also revealed the clear correlations between the field parameters and the spectral values for those classes falling in sunlight, while only aspect showed any significant correlation across the whole spectrum of classes. Those classes falling into shadow revealed no significant correlations.

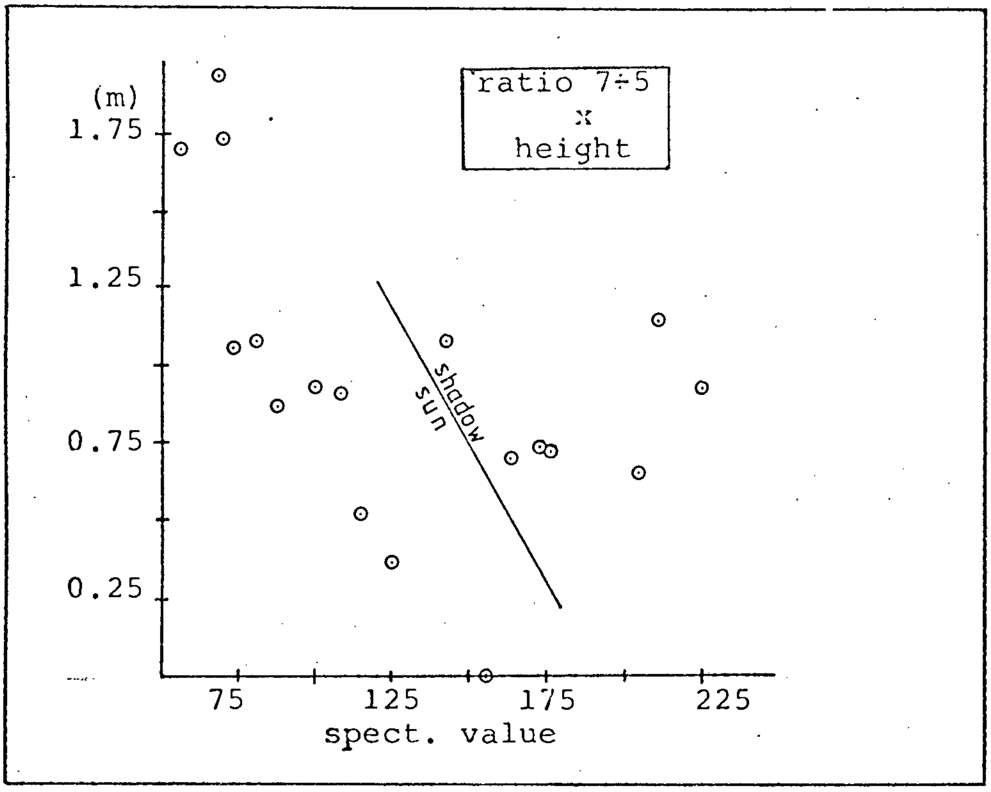
The correlation co-efficients and regression equations were therefore calculated on the ten sun irradiated classes only. For height, where class 18's (white sand) mean height was taken as 0, n was 11, and for aspect, all the classes except 18, 17 and 5, were included.

A study of the histograms of veld type, vegetation colour and background colour, indicated that there was a relationship (which was not quantifiable because of the arbitrary scale of measurements used), between the pixel values and veld type, as well as between the pixel values and vegetation colour.

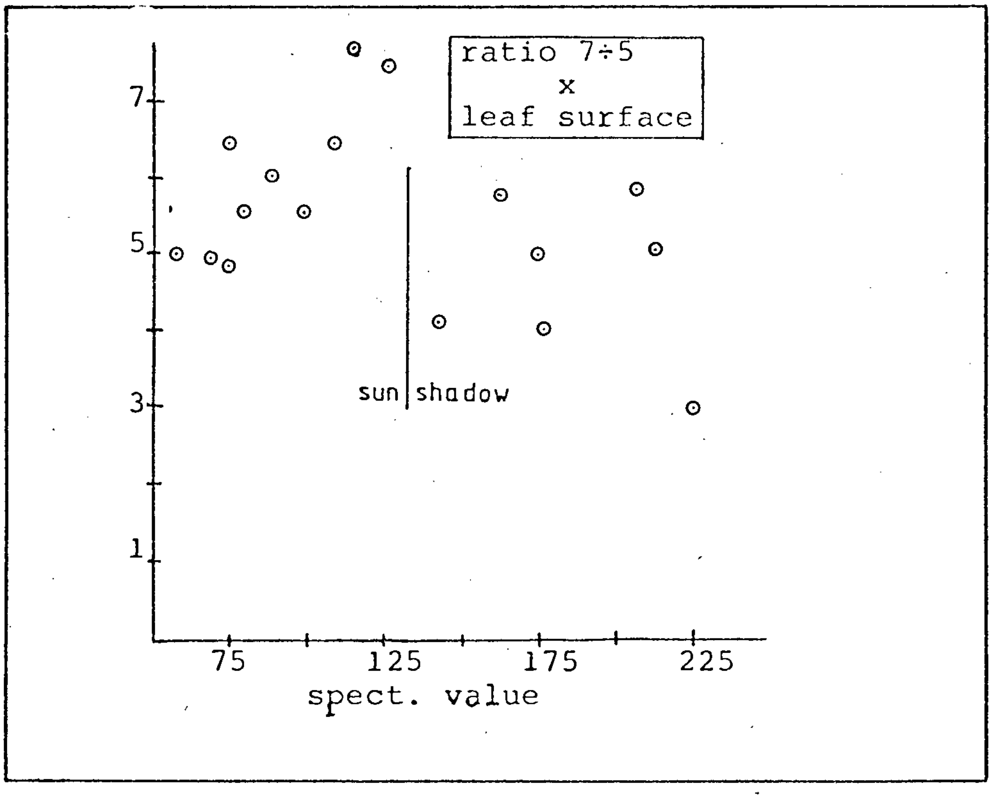
7.2.7.2. 7÷5 SHADOW.

The clustering of 7÷5 shadow produced 13 classes or clusters. Four of these 13 classes were not covered by field sampling and therefore contained no field parameters. They were thus ignored. Class 2 was also ignored, as it resulted

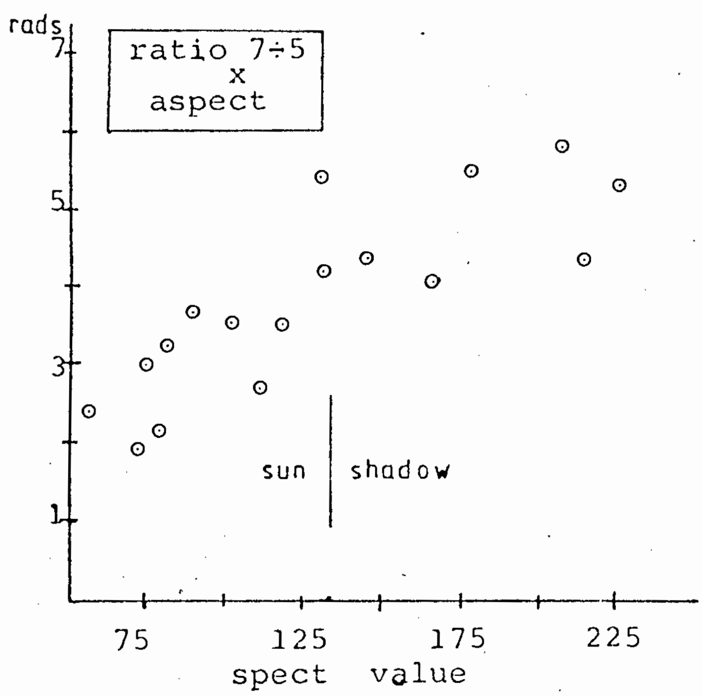
GRAPH NO.4



GRAPH NO.5



GRAPH NO.6


rads
7
5
3
1
ratio 7÷5
x
aspect
sun
shadow
75
125
175
225
spect value

from the masking operation, and contained all the pixels located in sunlight. The relatively poor correlations obtained from this image, supports the results of the ratio 7-5 image, where no trends, except aspect, were found in the shadowed areas. The correlation between pixel values, and both condition and percentage cover dead, and not any other parameter, is interesting, but a satisfactory explanation is not immediately obvious.

Table 7-5. REGRESSION EQUATIONS FOR 7÷5 SHADOW.

Aspect	= 0.04(7÷5 shadow)- 0.88	n=9	r= 0.69*
Veld Condition	=-0.05(7÷5 shadow)+ 12.11	n=9	r= 0.74*
%Cover Dead	=-0.24(7÷5 shadow)+ 50.24	n=9	r=-0.73*
%Cover Live	=-0.68(7÷5 shadow)+163.51	n=9	r=-0.27
%Cover Total	=-0.47(7÷5 shadow)+680.85	n=9	r=-0.62

(7÷5 shadow) = spectral value of ratio 7÷5 shadow.
* = 95% significance level

A study of the histograms of veld type, vegetation colour and background colour, revealed that only background colour gave any indication of a relationship with the pixel values, but this was not quantifiable, owing to the arbitrary nature of the measurement scale used for this parameter.

7.2.7.3. 7÷5 NO SHADOW.

Table 7-6. REGRESSION EQUATIONS FOR 7÷5 NO SHADOW.

Height =-2.5(7÷5 no shadow)+ 331.75	n=10	r=-0.97**
%Cover Dead =-0.24(7÷5 no shadow)+ 35.85	n=10	r=-0.91**
%Cover Live =-0.89(7÷5 no shadow)+ 141.6	n=10	r=-0.92**
%Cover Total =-1.06(7÷5 no shadow)+ 171.8	n=10	r=-0.94**
Veld Condition=-0.09(7÷5 no shadow)+ 11.6	n=10	r=-0.85**
Leaf Surface = 0.06(7÷5 no shadow)+ 1.38	n=9	r= 0.96** +
Fire Index =-10.0(7÷5 no shadow)+ 1290	n=10	r= 0.96**
Aspect = 0.04(7÷5 no shadow)- 0.58	n=9	r= 0.68*
Biomass Index = 2.5(7÷5 no shadow)- 329.3	n=10	r= 0.92**

(7÷5 no shadow) = spectral value of image (7÷5 no shadow).

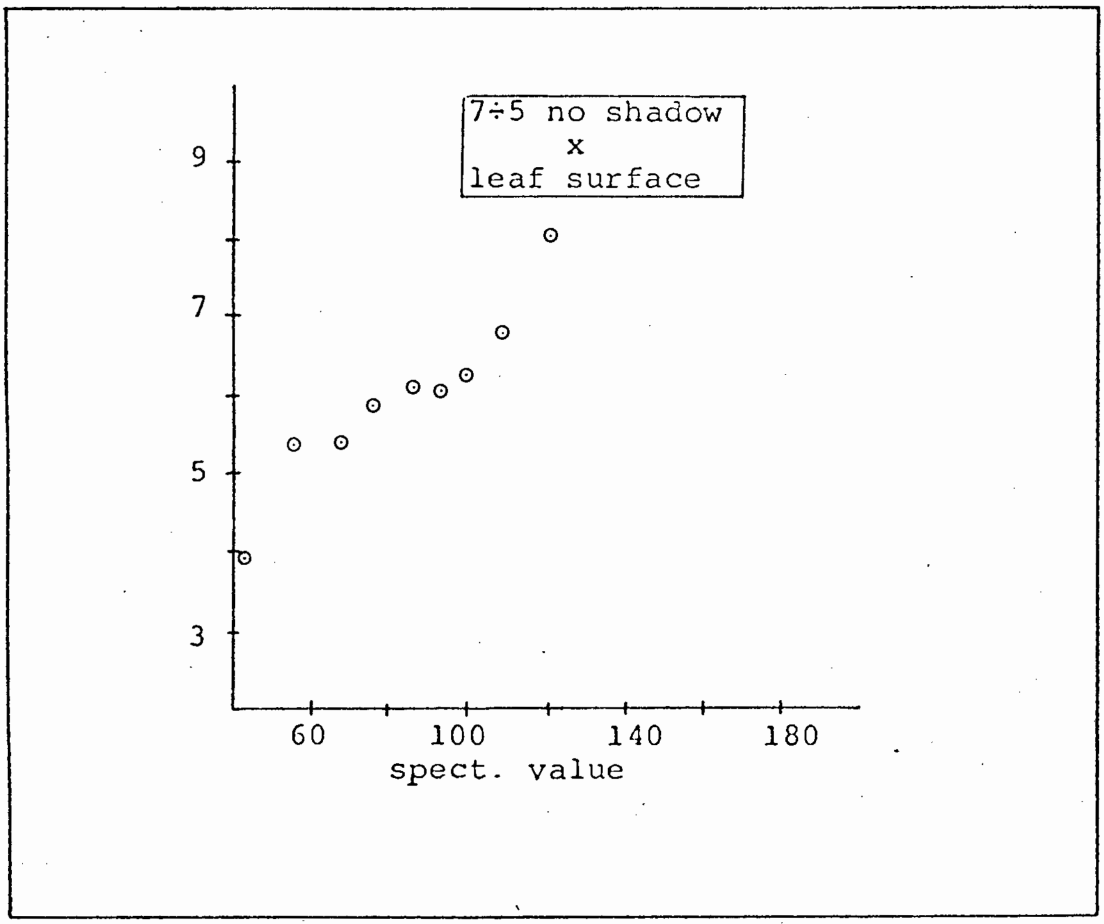
** = 99% significance level

* = 95% significance level

\+ = see Graph No.7.

This image (7÷5 no shadow) gave 12 classes, when clustered by the task "itclus". Class 12 was identified as white sand with the aid of aerial photographs, and was therefore given a value of zero for all the vegetation field parameters, except leaf surface. Class 2 contained all the pixels falling in shadowed areas, and class 7 contained no field measurements. Both these classes were excluded from the analysis. The strong correlations obtained from this image are comparable with those obtained from the sun irradiated classes of the total image (see Table 7-4). The fact that the weak correlation obtained from aspect and the absence of

GRAPH NO.7



any meaningful correlation with slope and reflective index, seems to indicate the success of the ratioing operation, in removing the topographical effect for areas irradiated by direct sunlight. This image gave slightly better correlation co-efficients than the image containing the shadowed areas. This can possibly be attributed to the spectral data of the image containing no shadow, being more normally distributed and therefore more suitable for analysis by the task "itclus".

From the histograms of veld type, vegetation colour and background colour, only veld type and vegetation colour showed indications of a relationship with the spectral values. These relationships could not be parametrically evaluated, owing to the arbitrary nature of the field measurements.

7.2.8. IMAGE 6÷5.

This image was created in the same way as the 7÷5 image, band 6 being used instead of band 7. Only the masked image, resulting in the shadow and water free image (6÷5 no shadow), was analysed. The significant regression equations and correlation co-efficients for this image are given in Table 7-7.

This image gave nine classes when clustered. Class 2 contained all the pixels located in shadowed areas, and was thus excluded from the analysis. These results support the finding that ratio removes the topographic effect for sun radiated areas. Strong correlations were evident for all vegetation field parameters.

Table 7-7. REGRESSION EQUATIONS FOR 6÷5 NO SHADOW.

Height	= 2.5(6÷5 no shadow)- 301.5	n=8 r= 0.96** +
%Cover Dead	= 0.18(6÷5 no shadow)- 15.5	n=8 r= 0.91** +
%Cover Live	= 0.70(6÷5 no shadow)- 42.3	n=8 r= 0.95** +
%Cover Total	= 0.77(6÷5 no shadow)- 50	n=8 r= 0.90** +
Veld Condition	= 0.06(6÷5 no shadow)- 5.2	n=8 r= 0.87** +
Leaf Surface	= 0.06(6÷5 no shadow)+ 16.5	n=8 r=-0.91** +
Biomass Index	= 2.50(6÷5 no shadow)- 322.5	n=8 r= 0.96**
Fire Index	= 8.33(6÷5 no shadow)- 1008	n=8 r= 0.98**

(6÷5 no shadow) = spectral value of the image (6÷5 no shadow).

** = 99% sigificance level

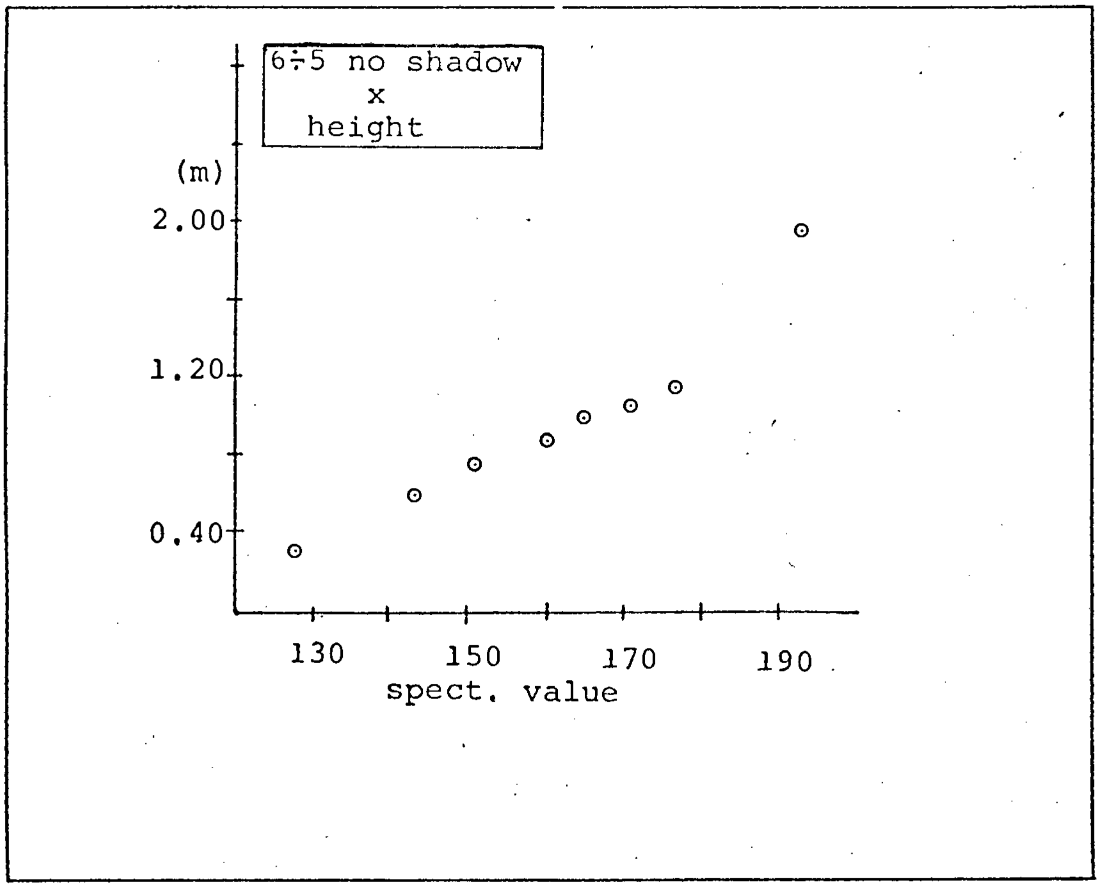
+ = see Graph No.8,9,10 & 11.

This image also indicated the existence of a relationship of veld type and vegetation colour with the spectral values. These were however not evaluated.

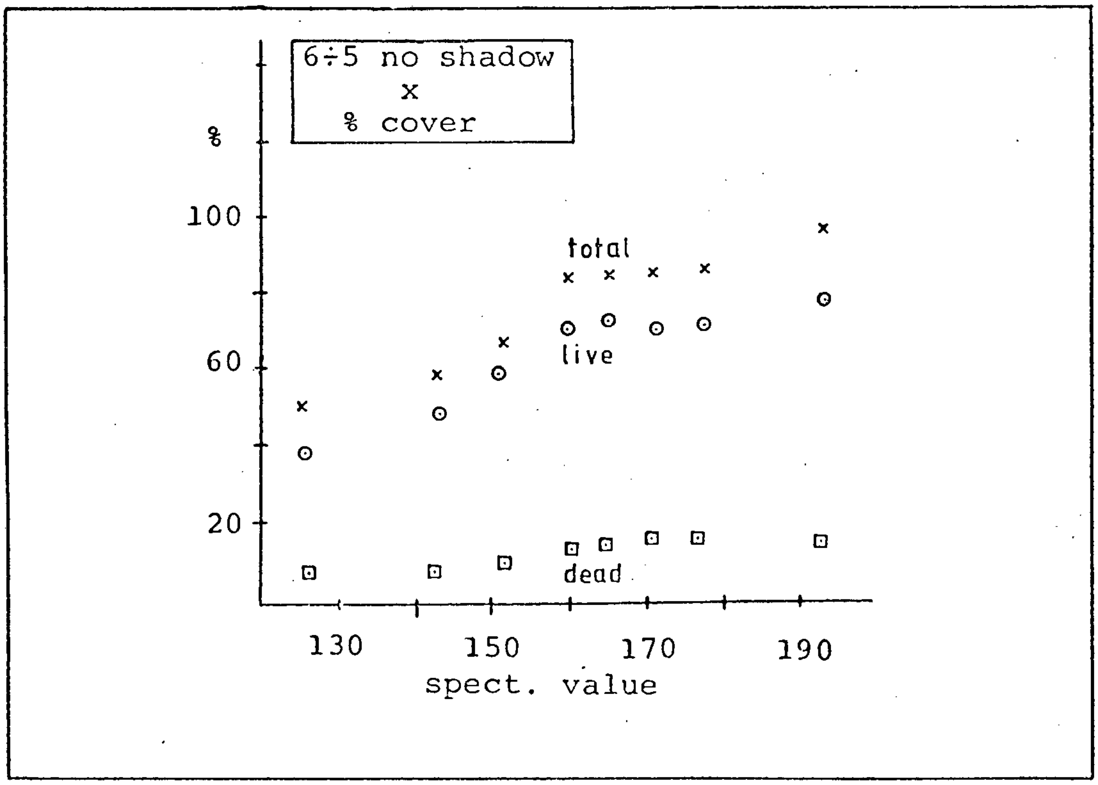
7.2.9. RATIO 6÷(4+5).

To create this ratio, the task "arithm" was used to add the values of bands 4 and 5. The task "ratio" from old Pips, was used to divide the values of band 6 by this sum, and to take the arctan function of the results. The arctan functions formed the ratioed image.

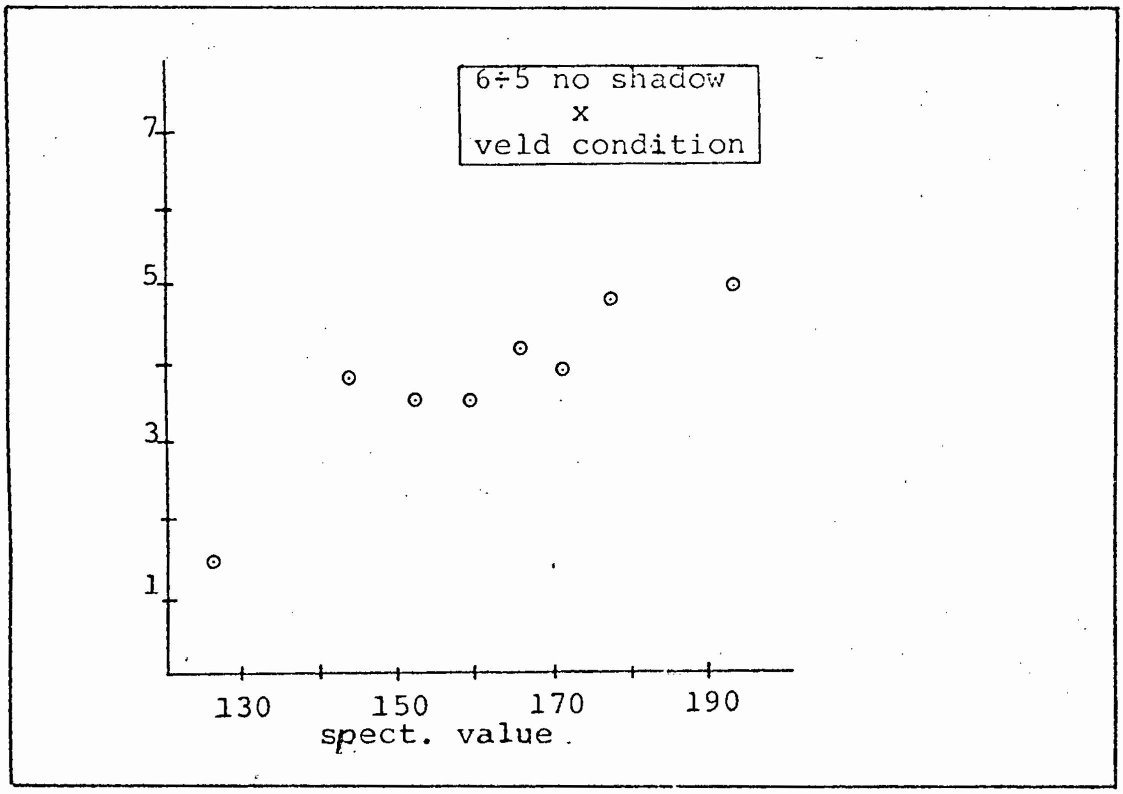
GRAPH NO.8



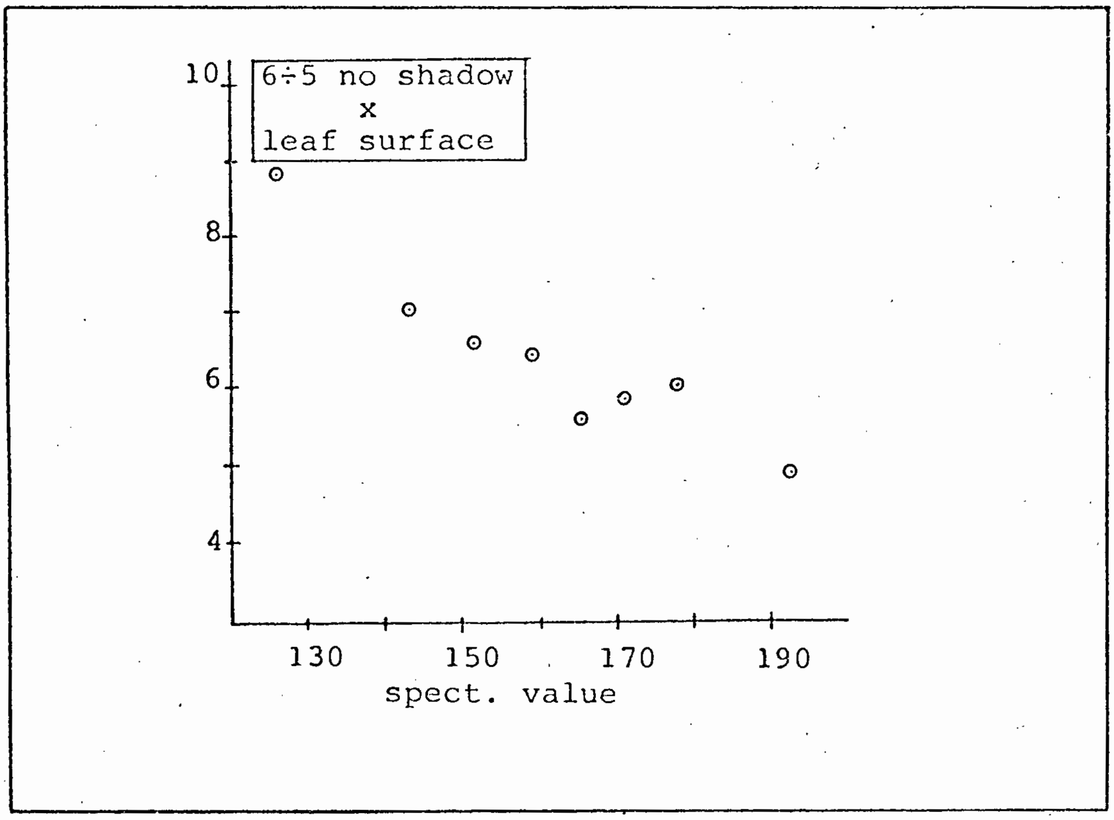
GRAPH NO.9



GRAPH NO.10



GRAPH NO.11



A mask was then applied to this image, so that the resultant image contained only those pixels located in areas receiving direct sun radiation. This image (6÷4+5 no shadow) was analysed. The regression equations and correlation co-efficients are given in Table 7-8.

Table 7-8. REGRESSION EQUATIONS FOR 6-4+5 NO SHADOW

Height	= 2.5(6÷4+5 no shadow)- 172.5	n=10	r= 0.93**	
%Cover Dead	= 52 log(6÷4+5 no shadow)- 92.4	n=10	r= 0.92**	
%Cover Live	= 198 log(6÷4+5 no shadow)- 344	n=10	r= 0.84**	
%Cover Total	= 246 log(6÷4+5 no shadow)- 429	n=10	r= 0.85**	
Veld Condition	= 0.07(6÷4+5 no shadow)- 3.9	n=10	r= 0.81**	
Leaf Surface	=-0.07(6÷4+5 no shadow)+ 14.2	n=10	r= 0.83**	+
Biomass Index	= 2.33(6÷4+5 no shadow)- 174.4	n=10	r= 0.95**	+
Fire Index	= 7.69(6÷4+5 no shadow)- 546	n=10	r= 0.92**	

(6÷4+5 no shadow) = spectral value of ratio 6÷(4+5)no shadow.

** = 99% significance level

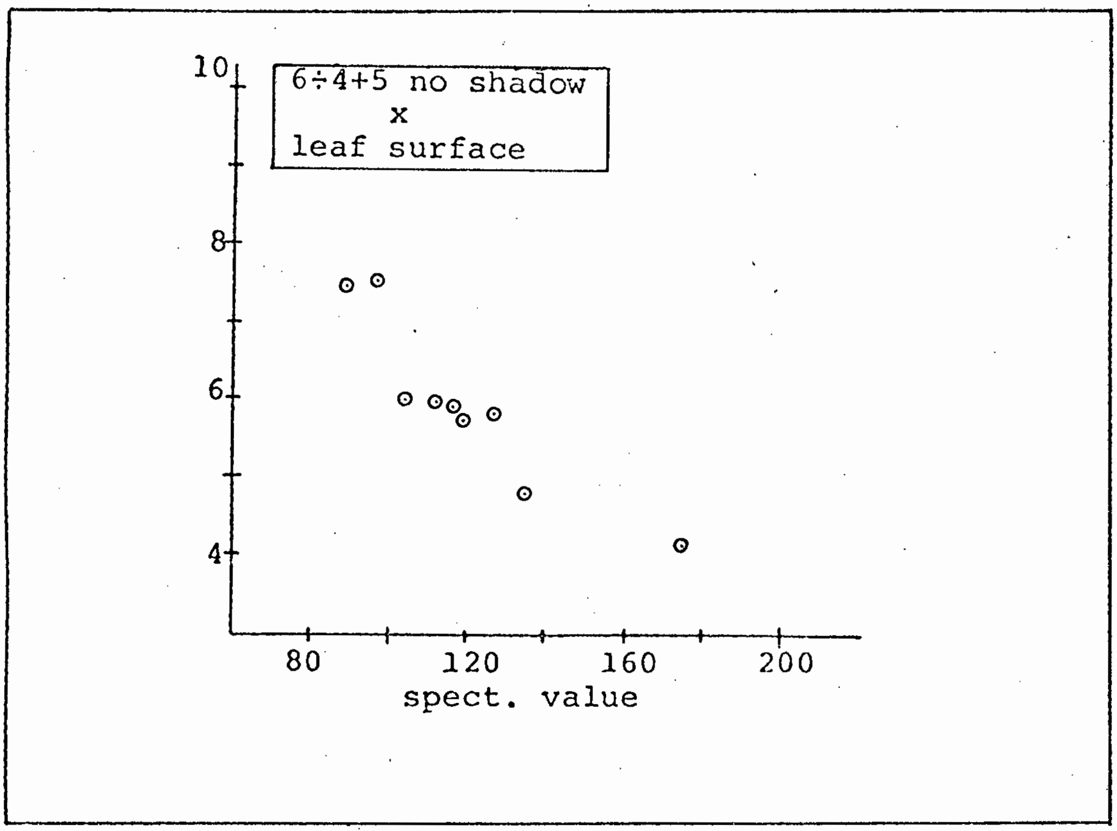
* = 95% significance level

\+ = see Graph No.12 & 13.

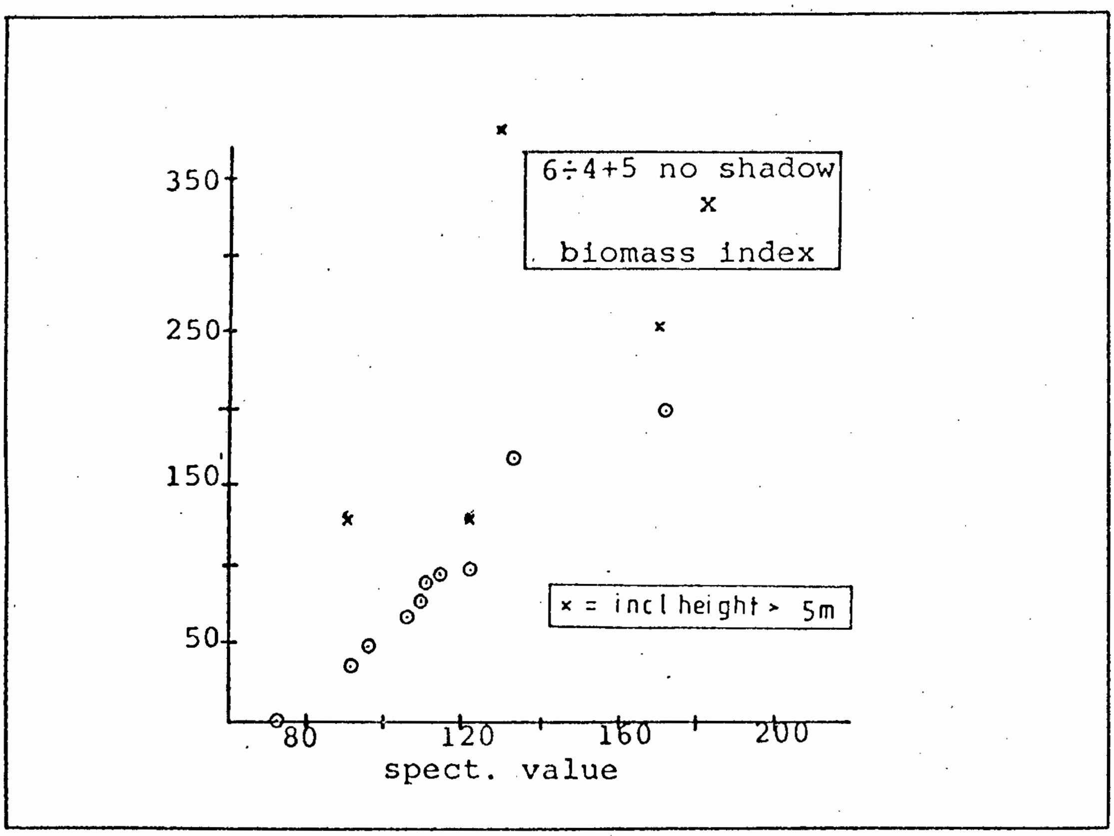
The image correlates well with height and therefore also biomass index and fire index. The absence of any significant correlation with aspect, slope or reflective index, illustrates that this ratio also removes the influence of topography on sun irradiated areas.

This image shows indications of a relationship between veld type, background colour and the pixel values. These were

GRAPH NO.12



GRAPH NO.13



not numerically evaluated either.

7.2.10. RATIO 7÷(4+5).

This image was created in the same way as the above image, except that band 6 was replaced by band 7. The same mask was placed on the image and a shadow/water free image (7÷4+5 no shadow) resulted, which was then analysed. The significant regression equations and correlation co-efficients are given in Table 7-9.

Table 7-9. REGRESSION EQUATIONS FOR 7÷4+5 NO SHADOW.

Height	= 2.33(7÷4+5 no shadow)- 160.5	n=10	r= 0.97**
%Cover Dead	= 28.3 log(7÷4+5 no shadow)- 44.5	n=10	r= 0.64 +
%Cover Live	= 176 log(7÷4+5 no shadow)- 297	n=10	r= 0.90** +
%Cover Total	= 209 log(7÷4+5 no shadow)- 353	n=10	r= 0.88** +
Veld Condition	= 0.06(7÷4+5 no shadow)- 3.4	n=10	r= 0.92**
Leaf Surface	=-0.06(7÷4+5 no shadow)- 13.7	n=9	r=-0.85**
Biomass Index	= 2.38(7÷4+5 no shadow)- 176.2	n=10	r= 0.96** +
Fire Index	= 8.33(7÷4+5 no shadow)- 591.7	n=10	r= 0.98** +
Slope	= 0.06(7÷4+5 no shadow)- 10.2	n= 9	r=-0.74 *
Aspect	= 0.003(7÷4+5 no shadow)- 0.2	n= 9	r= 0.73 *

(7÷4+5 no shadow) = spectral value of ratio 7÷4+5 no shadow.

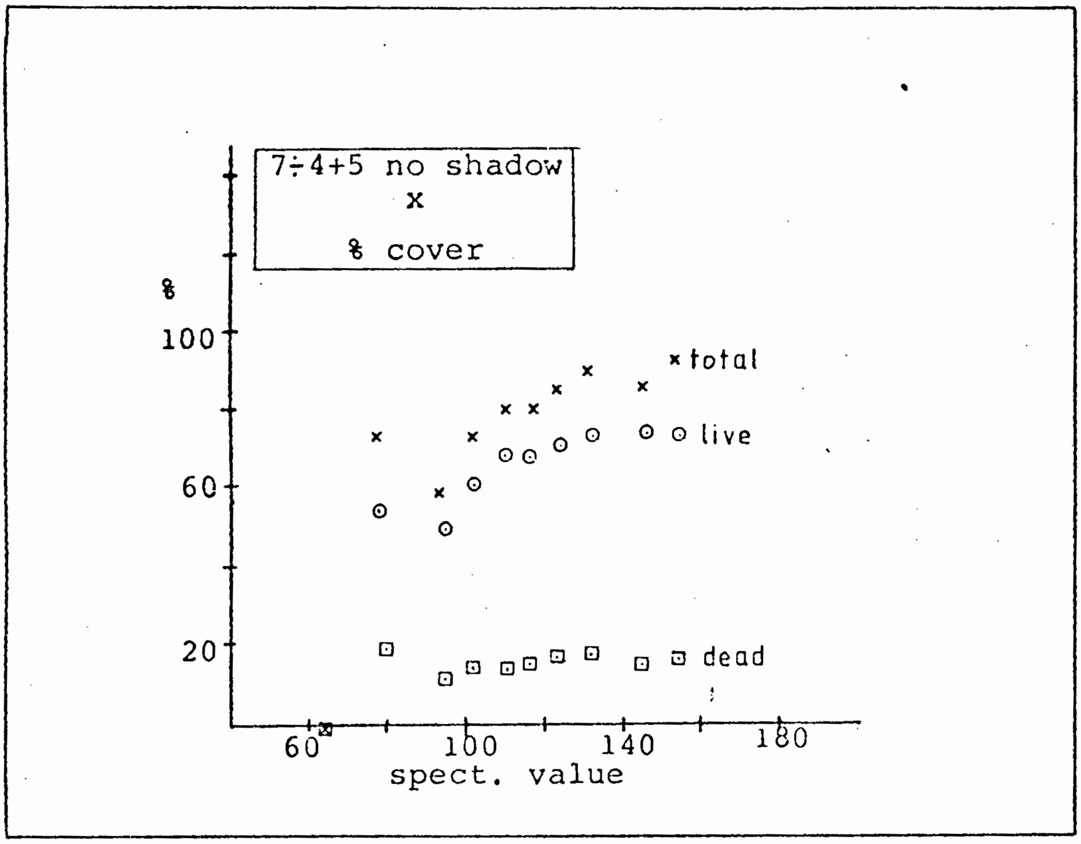
** = 99% signifance level

* = 95% significance level

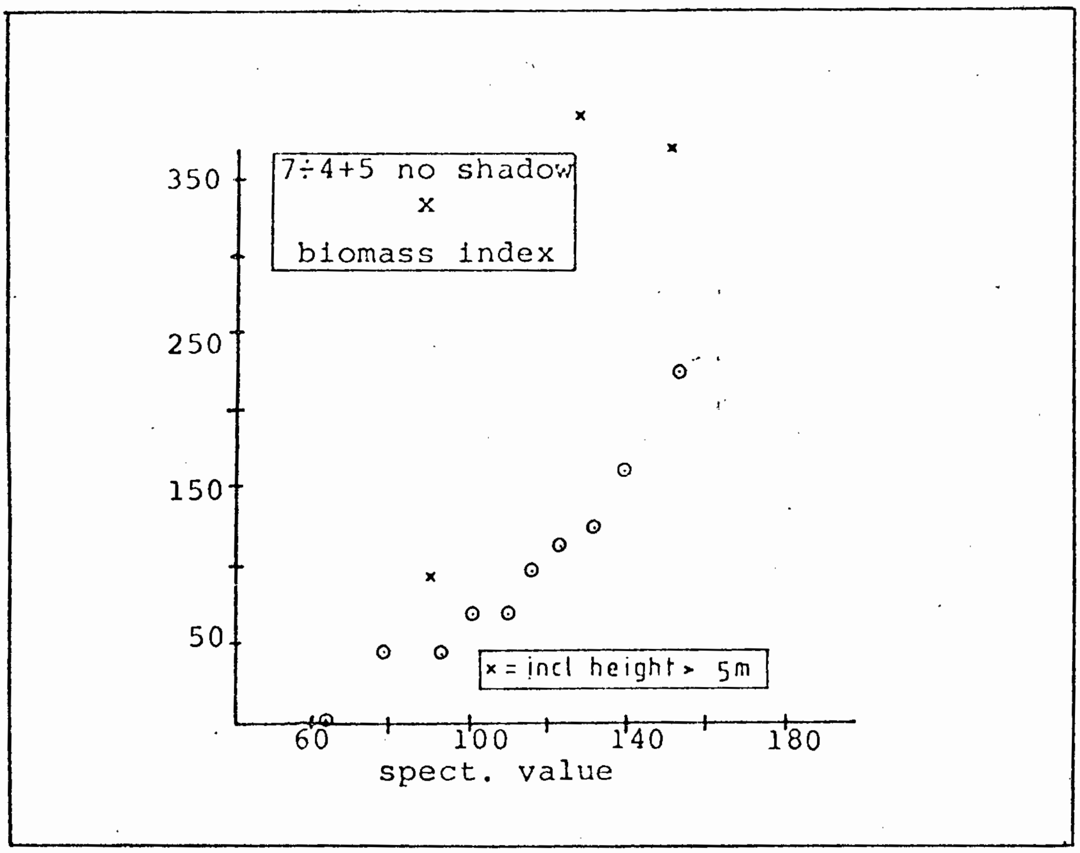
\+ = see Graph No.14,15 & 16.

The cluster analysis of this image resulted in eleven

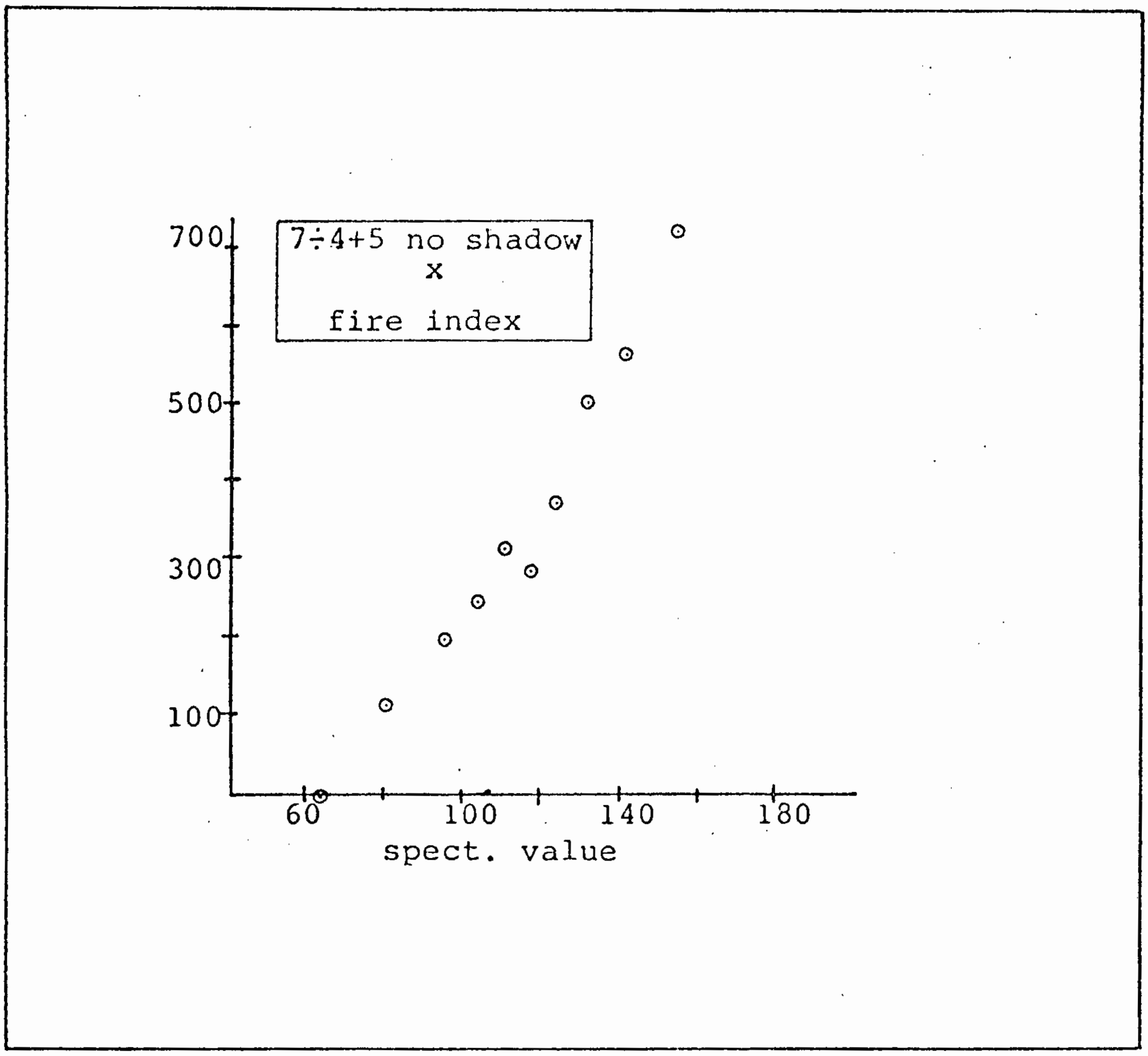
GRAPH NO.14



GRAPH NO.15



GRAPH NO.16



7÷4+5 no shadow
x
fire index
700
500
300
100
60
100
140
180
spect. value

classes. Class 2 contained the shadow and water pixels. Class 10 was identified from the aerial photographs as white sand and was given the appropriate values for the various field parameters, for plotting on the graphs, and for calculating the correlation and regression statistics. Leaf surface, slope and aspect were the only field parameters, where a value for class 10 could not be estimated. These equations are therefore based on nine pairs of values and not ten. The significantly high correlations of slope, aspect and biomass index with the spectral values, makes this ratio a suitable candidate for the mapping of the fire index.

This ratio was also the only ratio to show some degree of correlation between the spectral values and all three of the field parameters, veld type, vegetation colour and background colour. Owing to the arbitrary nature of the measurement scales of these parameters, these relationships could however not be quantified.

7.2.11. RATIO (7-5) ÷ (7+5).

This ratio was created by using the task "arithm" to subtract band 5 values from the values of band 7 and then also for adding them together so creating two images. With the aid of the "ratio" task from old Pips, the two images were divided and the value of the arctan function of the result, gave this ratioed image. The formula for this ratio can be summarized as:

Image = arctan (band 7 - band 5) ÷ (band 7 + band 5).

The shadow/water and shadow/water free masks were again used on this image, and all three of the resultant images were examined for significant correlations.

7.2.11.1. RATIO (7-5)÷(7+5) SHADOW ONLY.

This image contained only those pixels falling in shadowed areas or on water bodies. Only one significant correlation was found. This was for veld condition. The equation:

Veld Condition = 0.07 [(7-5)÷(7+5)shadow only] - 1.1

was established from eight points, with a correlation co-efficient of 0.71 significant at the 99% level.

7.2.12. RATIO (7-5) ÷ (7+5) TOTAL.

This image comprises the unmasked image containing both the shadowed and sunlit areas. The cluster analysis resulted in thirteen classes of which three contained no field measurements. These were excluded from the correlation and regression analysis. Classes 11, 7, 4, 10 and 6 were identified as classes containing pixels located in shadow areas and were thus examined separately, if the graphical plot indicated that this would be desirable (see Graph No.16.).

The significant regression equations and correlation co-efficients are given in Table 7-10.

Table 7-10. REGRESSION EQUATIONS FOR (7-5) ÷ (7+5) TOTAL.

Height	= 7.94[(7-5)÷(7+5)total]-870.2	s n=6 r= 0.82*
%Cover Live	= 0.15[(7-5)÷(7+5)total]+ 58.9	sd n=4 r= 0.84
%Cover Live	= 0.84[(7-5)÷(7+5)total]- 41.9	s n=6 r= 0.94**
%Cover Total	= 0.22[(7-5)÷(7+5)total]+ 68.3	sd n=4 r= 0.88 +
%Cover Total	= 1.00[(7-5)÷(7+5)total]- 48.3	s n=6 r= 0.96**+
Veld Condition	= 0.11[(7-5)÷(7+5)total]- 10.2	s n=6 r= 0.89**
Leaf Surface	=-0.08[(7-5)÷(7+5)total]+ 16.3	s n=6 r= 0.97**
Biomass Index	= 8.13[(7-5)÷(7+5)total]- 906.1	s n=6 r= 0.82 *
Fire Index	= 25.3[(7-5)÷(7+5)total]- 2749	s n=6 r= 0.79
Reflective Index	= 0.003[(7-5)÷(7+5)total]+ 0.23	n=10 r= 0.67*
Aspect	=-0.03[(7-5)÷(7+5)total]- 7.1	n=10 r=-0.73

[(7-5)÷(7+5)total] = spectral value of [(7-5)÷(7+5)total]

s = sun classes only

sd = shadow classes only

** = 99% significance level

* = 95% significance level

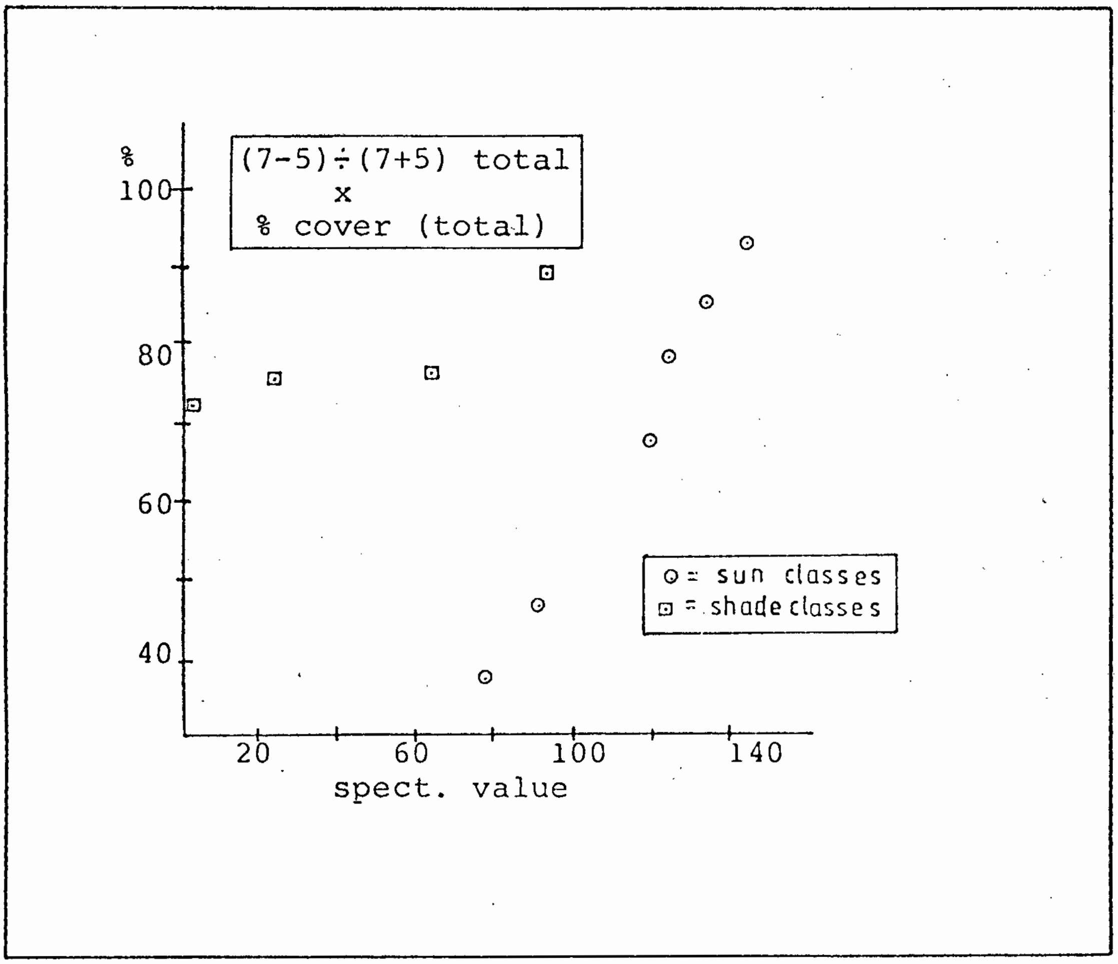
\+ = see Graph No.17 .

Percentage Cover Live and Percentage Cover Total were the only parameters to show any degree of correlation in the shadowed areas.

7.2.13. RATIO (7-5) ÷ (7+5) NO SHADOW.

This image resulted from the masking out of the water and shadow areas. The clustering analysis resulted in eight

GRAPH NO.17


%
100
80
60
40
(7-5)÷(7+5) total
x
% cover (total)
⊙= sun classes
⊡ = shade classes
20
60
100
140
spect. value

classes. Class 3 contained all the pixels falling into shadowed areas and all the pixels representing water bodies. This class was therefore excluded from the regression and correlation statistics. Class 7 was identified as white sand, and estimated field parameters for this class were used in the analysis, where possible. The significant regression equations and correlation co-efficients for this image are given in Table 7-11.

Table 7-11. REGRESSION EQUATIONS FOR (7-5) ÷ (7+5) NO SHADOW.

Height	= 3.04[(7-5)÷(7+5)no shadow]- 286.9	n=7	r= 0.95**
%Cover Dead	= 0.39[(7-5)÷(7+5)no shadow]- 34.9	n=7	r= 0.80*
%Cover Live	= 1.45[(7-5)÷(7+5)no shadow]- 122.3	n=7	r= 0.95**
%Cover Total	= 1.79[(7-5)÷(7+5)no shadow]- 150.2	n=7	r= 0.94**
Veld Condition	= 0.09[(7-5)÷(7+5)no shadow]- 7.3	n=7	r= 0.95**
Leaf Surface	=-0.09[(7-5)÷(7+5)no shadow]+ 17.3	n=6	r= 0.95**
Biomass Index	= 3.13[(7-5)÷(7+5)no shadow]- 307	n=7	r= 0.93**
Fire Index	= 11.4[(7-5)÷(7+5)no shadow]- 1105	n=7	r= 0,93**
Aspect	=-0.05[(7-5)÷(7+5)no shadow]+ 9.7	n=6	r=-0.77*

[(7-5)÷(7+5)no shadow]=spectral value of [(7-5)÷(7+5)no shadow].

** = 99% significance level

* = 95% significance level

This ratio is generally well suited for measuring vegetation parameters in fynbos. The removing of the shadow/water component, appears to improve the accuracy of the clustering procedure as a comparison of Table 7-11 and 7-12 illustrates.

Veld type and vegetation colour showed some correlation with the spectral values of this image, but was not quantifiable.

7.2.14. RATIO (6-5) ÷ (6+5).

This ratio was created in the same way as the previous ratio, (7-5)÷(7+5), except that band 6 was used instead of band 7. The same mask for the removal of the water/shadow areas was used and the image, the (6-5)÷(6+5) shadow and water free image, resulted. The significant results of the regression and correlation analysis are given in Table 7-12.

Table 7-12. REGRESSION EQUATIONS FOR (6-5) ÷ (6+5) NO SHADOW.

Height	= 2.33[(6-5)÷(6+5)]+ 19.1	n=7	r= 0.94** +
%Cover Dead	= 14.7 log[(6-5)÷(6+5)]- 7.1	n=7	r= 0.60
%Cover Live	= 39.6 log[(6-5)÷(6+5)]+ 6.2	n=7	r= 0.97**
%Cover Total	= 55.3 log[(6-5)÷(6+5)]- 3.3	n=7	r= 0.97**
Veld Condition	= 0.04[(6-5)÷(6+5)]+ 2.3	n=7	r= 0.86* +
Leaf Surface	=-0.04[(6-5)÷(6+5)]+ 7.5	n=7	r=-0.92** +
Biomass Index	= 2.56[(6-5)÷(6+5)]- 3.2	n=7	r= 0.95**
Fire Index	= 12.5[(6-5)÷(6+5)]- 87.9	n=7	r= 0.94**

[(6-5)÷(6+5)] = spectral value of ratio [(6-5)÷(6+5)].

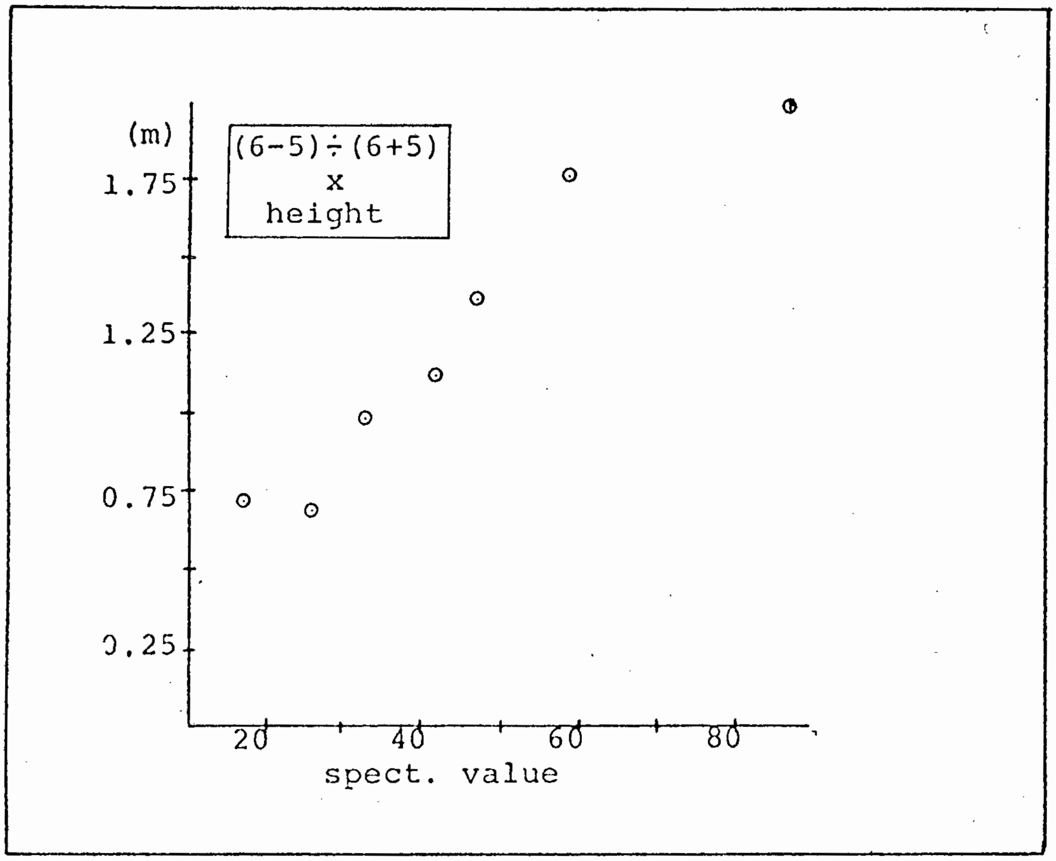
** = 99% significance level

* = 95% significance level

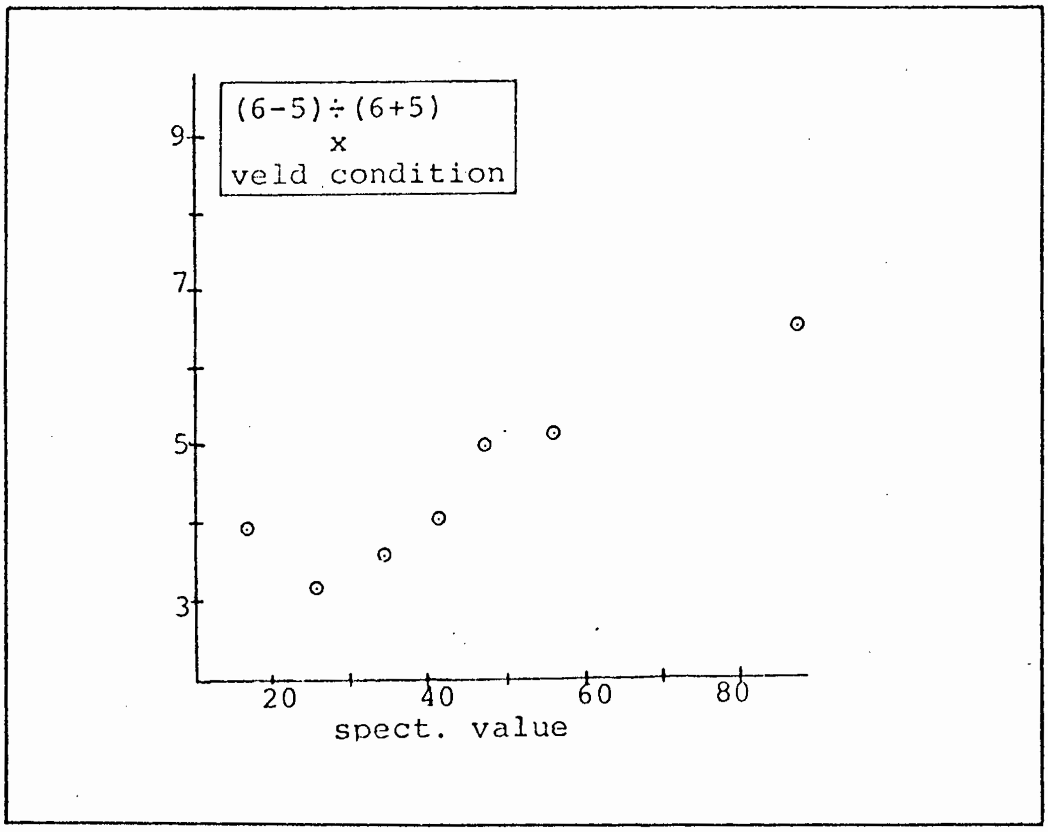
\+ = see Graph No.18,19 & 20.

This ratio appears well suited for the mapping of vegetation height, percentage cover and therefore biomass, as aspect

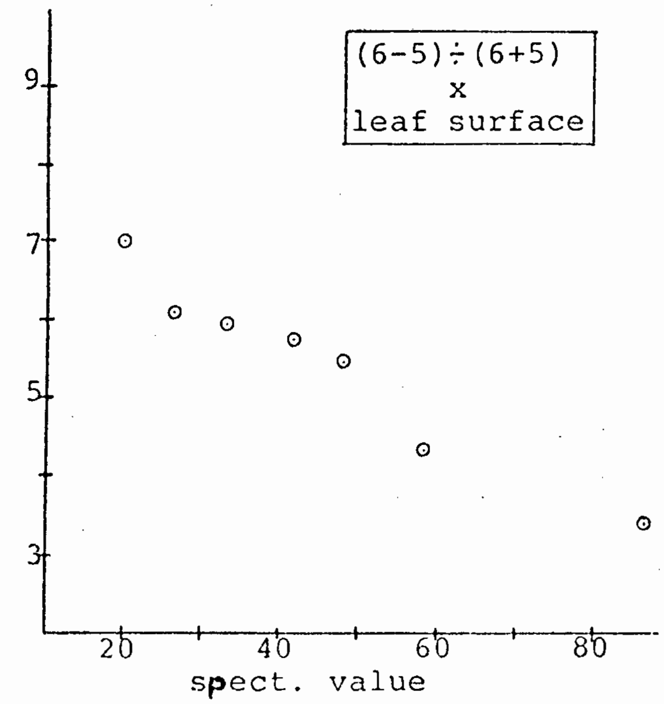
GRAPH NO.18



GRAPH NO.19



GRAPH NO.20



and slope, and therefore reflective index, are poorly correlated. The adverse influence of topography on sun irradiated areas is therefore neutralized by this ratio.

Here again, veld type and vegetation colour show some degree of correlation with the spectral values of this ratio, but were not evaluated.

7.2.15. VEGETATION INDEXES.

Three images were created using all four MSS bands and the transformations suggested by Kauth and Thomas (1976). These transformations were obtained experimentally and reflect the greenness and yellowness of the vegetation and the soil brightness, respectively. The formula for these transformations are:

1. Green vegetation index (GVI) =

   -0.29(band 4) -0.53(band 5) -0.6(band 6) +0.49(band 7)

2. Yellow vegetation index (YVI) =

   -0.82(band 4) +0.53(band 5) -0.05(band 6) +0.19(band 7)

3. Soil Brightness Index (SBI) =

   0.43(band 4) +0.63(band 5) -0.59(band 6) +0.25(band 7)

The task "arithm" was used to perform these transformations and the mathematical equations were broken down into components, in such a way as to try to keep the result of each step within the range 0 to 255, so minimizing the number of truncations performed by the Pips programme. To reduce the number of truncated values even further, the shadow water image mask was appied to the four MSS bands, before the transformations were performed. This resulted in the images being water and shadow free, with those pixels falling on water or in shadow being given a value of zero, so facilitating the transformation procedure, without the result going out of range.

This resulted in only 22 truncations for the SBI, 23 for the GVI and 734 for the YVI. The YVI was discarded as having too many values truncated, causing an unacceptable amount of distortion to the image. The cluster analysis of SBI resulted in three classes. Class 3 was identified as white sand, class 2 as water and shadow and class 1 as the rest of the image. This image was therefore not further analysed. The cluster analysis of GVI resulted in seven classes. Class 3 contained the water/shadow pixels. The results of the correlation and regression analysis are given in Table 7-13.

Table 7-13. REGRESSION EQUATIONS FOR GVI

Height	= 2.37(GVI)+ 36.7	n=6	r= 0.96**	+
%Cover Total	= 45.8 log(GVI)+ 14.7	n=6	r= 0.95**	+
%Cover Live	= 30.5 log(GVI)+ 22.7	n=6	r= 0.93**	+
%Cover Dead	= 15.2 log(GVI)- 8.0	n=6	r= 0.85**	+
Leaf Surface	=-0.05(GVI)+ 7.6	n=6	r=-0.92**	+
Biomass Index	= 2.58(GVI)- 17.9	n=6	r= 0.98**	+
Fire Index	= 6.86(GVI)- 154.9	n=6	r= 0.88**	

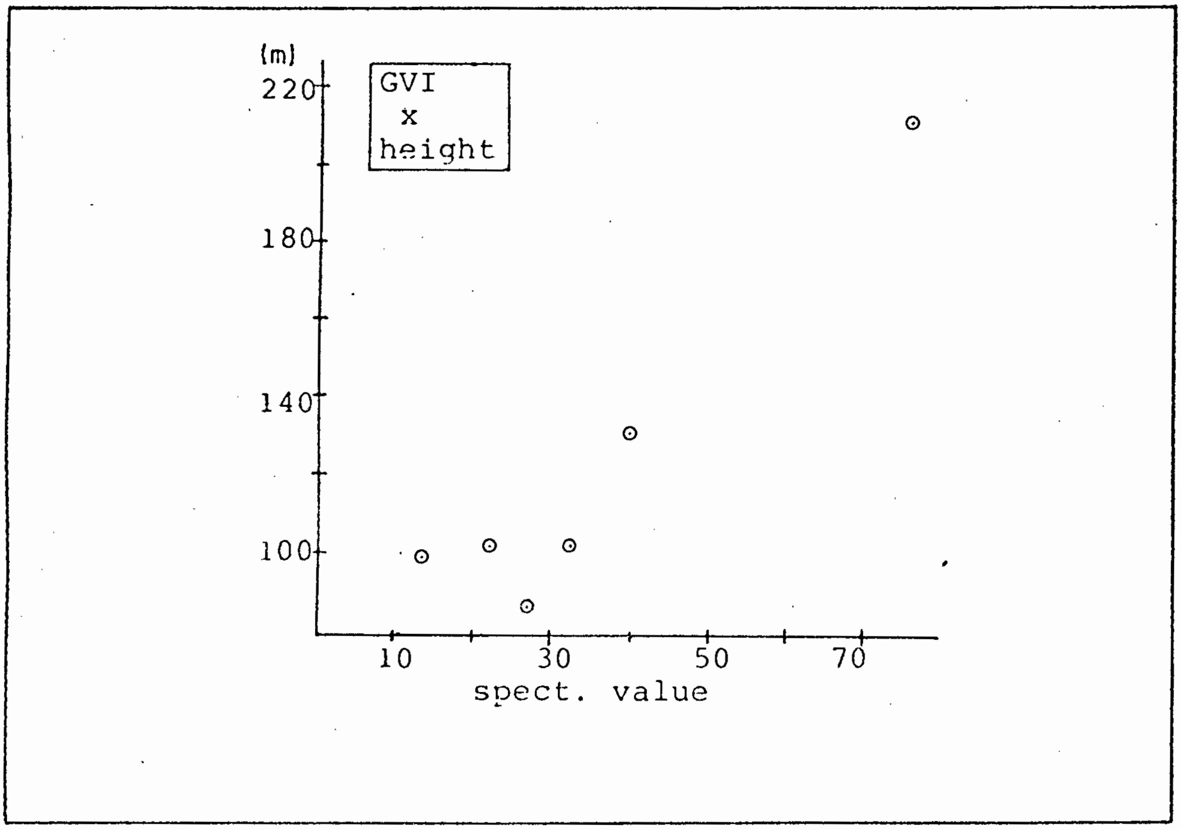
(GVI) = spectral value of index GVI.

** = 99% significance level

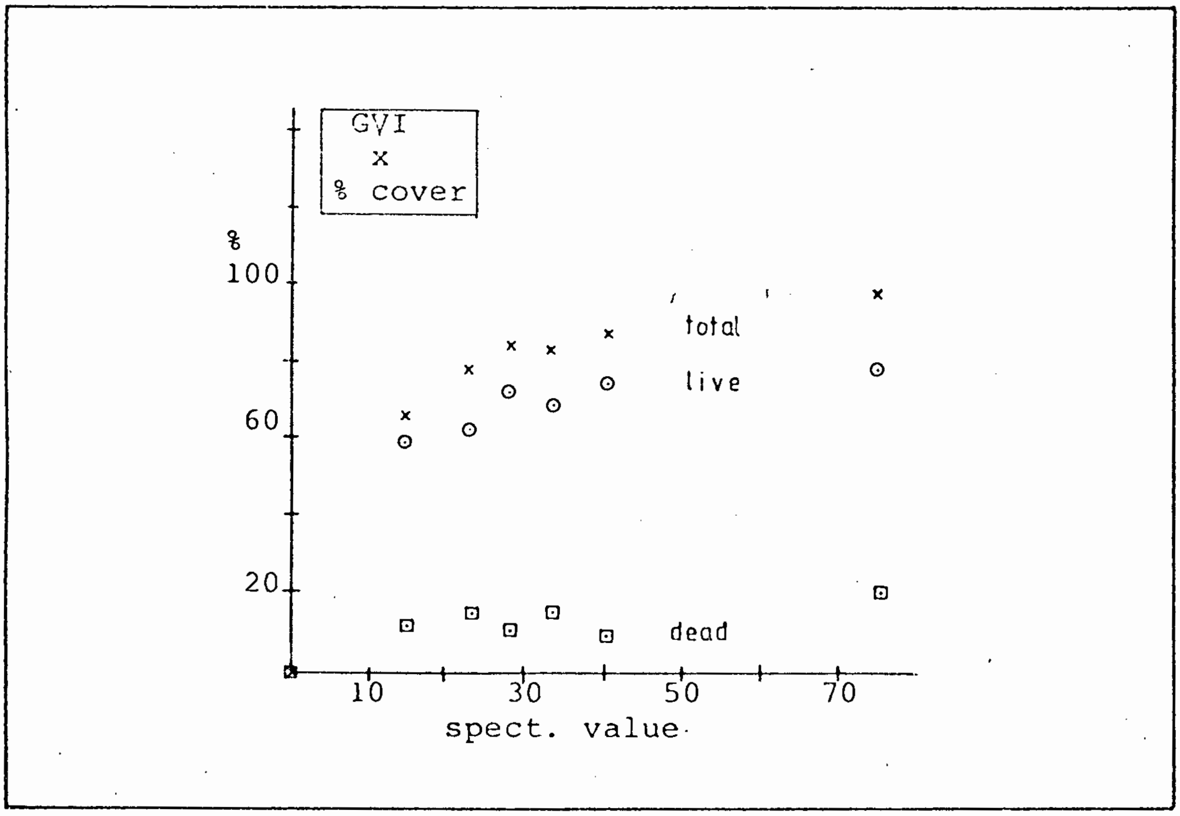
* = 95% significance level

+ = see Graph No.21,22,23 & 24.

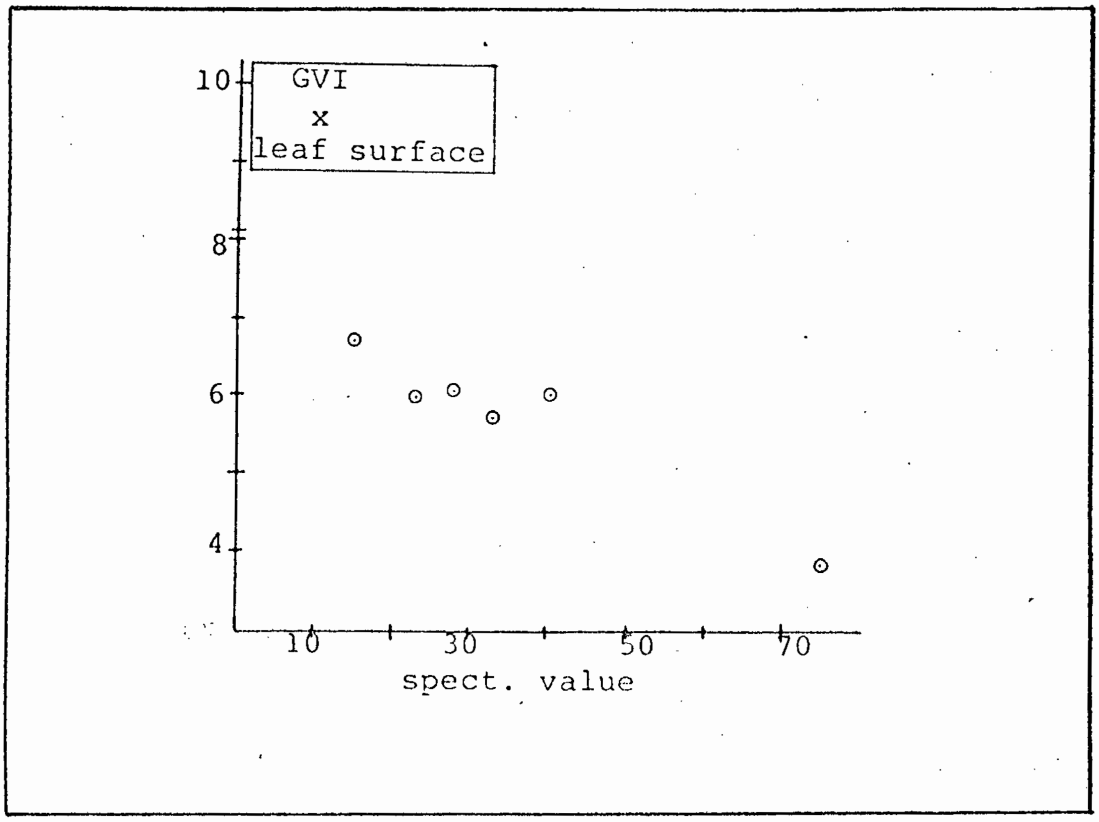
GRAPH NO.21



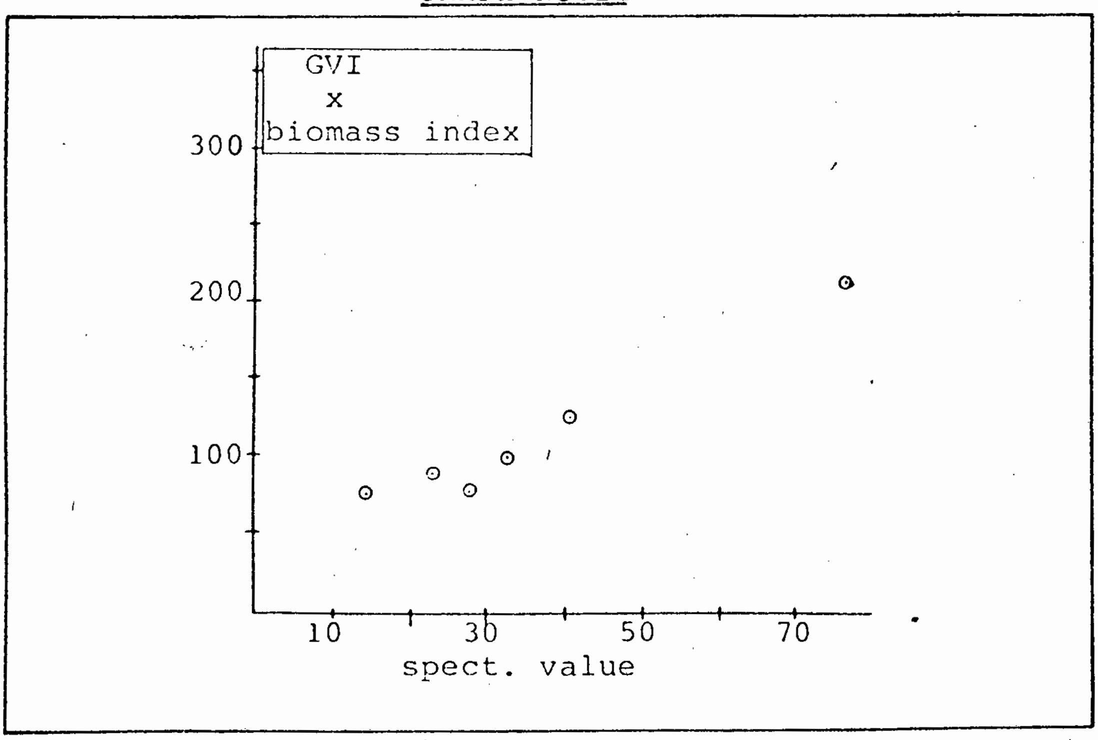
GRAPH NO.22



GRAPH NO.23



GRAPH NO.24



Pollock and Kanemasu (1979) report that it is suspected that foliage density is the dominant factor in determining the GVI. The high correlation of the GVI values with percentage cover seems to confirm this.

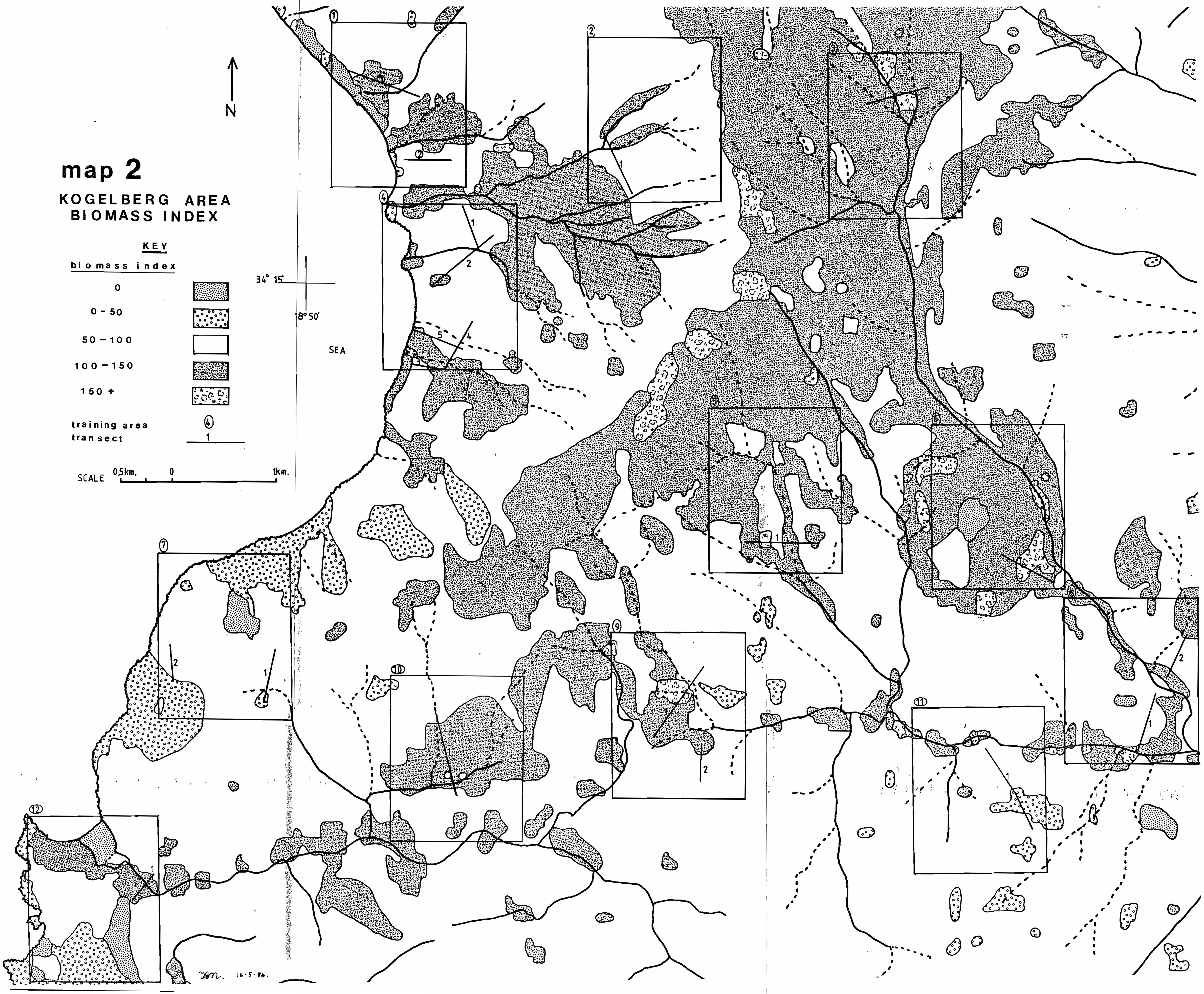
This index appears well suited for the mapping of the selected vegetation parameters in the fynbos. The histogram of veld type and vegetation colour also indicate some degree of correlation with the GVI values, but were not further evaluated.

7.3. THE THEMATIC MAP.

A thematic map showing the biomass index was produced from two of the ratios, selected for their strong correlation with the biomass index and weak correlation with slope, aspect and reflective index. The two images chosen were the GVI and the 6÷5 (no shadow).

Images containing no shadow were chosen and the shadowed areas were mapped by extrapolation from surrounding areas and from the aerial photographs and field inspections. This was done as no reliable classification was possible in the shadowed areas.

These images were clustered with the aid of the task "itclus", and with the aid of the task "stats", the resultant signatures were evaluated. The task "stats" prints a bispectral plot, showing the relationship between the spectral means of the classes of each image. It also prints


map 2
KOGELBERG AREA
BIOMASS INDEX
KEY
biomass index
0
0 - 50
50 - 100
100 - 150
150 +
training area
transect
SCALE 0,5km. 0 1km.
N
34° 15'
18° 50'
SEA

a table of the Jeffrey-Matusita distance and the transformed divergence statistics. (O'Donoghue et al,1983)

These statistics have a value of 0 to 2000 and show statistically how close together the selected two spectral classes are. A value of between 0 and 1000 indicates that the classes should be combined to form one class. A value of 1500 to 2000 indicates that the classes are distinct and a value of between 1000 and 1500 requires an analyst decision to be made, based on the ground reference data.

Based on the evaluation of the output from the task "stats", the task "edsig" was used to select and create the relevant signatures. Five signatures were created with the task "edsig" from the original twenty produced by the task "itclus". These signatures were then used to classify the images of the whole study area, using the task "maxlik". The task "predom" was used to remove noise from the classified image and to produce an aesthetically pleasing product. The map is shown on page 136.

This map was not parametrically evaluated as it was produced as an illustration only.

7.4. GENERAL DISCUSSION.

7.4.1. VARIANCE IN THE FIELD MEASUREMENTS.

The working scale used for this project was 1:25 000. At this scale, one pixel equals approximately one print character on the line printer print-out. The field measurements were collected every 25 metres, resulting in one to three data points being located in one pixel. In the regression and correlation analyses, this caused a large number of different field measurements to be averaged for comparison with the means of the spectral classes. Furthermore, the transsects along which the field data were collected, were placed to cross as many ecotones as possible. This resulted in the field measurements, grouped to each spectral class, having a large variance, which could have been reduced, had the transsects been placed in areas of homogeneous veld. A smaller pixel size, like the LANDSAT 4 thematic mapper pixel, would also have helped.

The difficulty in locating the exact position of a pixel on the ground in this terrain and the repeated transfer of the position of the trannsects from the ground onto an aerial photograph, then onto a map and finally onto the line printed print-out, all contribute to the distortion of the field data.

7.4.2. FIELD MEASUREMENTS.

The aim of this project was to obtain an indication of the value of LANDSAT MSS imagery for catchment management. For this reason only crude field measurements were taken. Generally the level of measurement proved satisfactory. Veld type, vegetation colour and background colour however gave disappointing results. Background colour was generally masked by the high degree of vegetation cover in the area and poor correlation with the spectral data could therefore be expected. Vegetation colour on the other hand, was too crudely measured to give any meaningful result. In the case of veld type, the reason for the poor results is not apparent. It could be the result of the vegetation classification system used, as most of the area was classified as one type, restio-shrub veld, only. The spectral uniqueness of the selected veld types was also not known and could be very similar, making the spectral distinctions between them difficult.

The use of a hand held spectrometer, calibrated to measure reflectance in the same wavelength bands as the LANDSAT MSS, would have been of assistance in checking the spectral uniqueness of the selected veld types. An instrument of this type was however not readily available for this study.

A vegetation classification system such as Taylors (1978), which can be related to leaf surface, which correlates well with the spectral data, would give better results. Taylor's system divides fynbos into a proteoid zone (broad leaf) and a restio-ericoid zone (narrow leaf). The hygrophylis zone could be subdivided into classes based on leaf size as well.

It should also be noted that the imagery used in this project was captured during summer as this minimized the shadow effects. A study of the spectral changes due to growth and flowering periods of the different components of fynbos, may reveal a more suitable season for image capture to distinguish the different veld types.

Fire index was included in the field parameters as it was regarded as important management information. It should however be noted, that slope alone does not correlate with the spectral data and its inclusion in the formula for fire index does not contribute to the value of the index. A more suitable way of introducing slope into the index, is by combining the spectral information, which correlates well with biomass and aspect, with other ancillary data such as a digital height model from which slope can be derived.

7.4.3. REGRESSION EQUATIONS AND VEGETATION MONITORING.

A LANDSAT image can contain values ranging from 0 to 255, (8 bit value) however, the pixel values relating to fynbos have a much narrower range. Jarman et al (1983) found for example, that for band 4, fynbos spectral values were restricted to values of below 35. The regression equations given in this project are based largely on a subset, the fynbos spectral values, of the range of values occurring on an image. It must therefore be assumed that these equations are applicable to fynbos, and possibly, to the study site only.

Furthermore, the time lapse between the image capture and the collection of field data against which the spectral data was correlated, was of considerable duration (20 months) and could further detract from the value of these equations. They are also based on a set of relatively crude field measurements, yet they clearly show the probable uses to which LANDSAT MSS data can be put, to aid the catchment management process.

One of the uses to which this data can be put, is to aid the monitoring operations being conducted in the catchment areas.

The mountain catchment areas of the Western Cape Province are divided into management sub-units of 500 to 2000 hectares each, called compartments. The present management policy involves burning the vegetation of these compartments at regular intervals, with the main aim of maintaining the vegetation in a healthy and virile state. One of the functions of the monitoring programme is to obtain an indication of when the veld has reached a state of maturity, suitable for burning. It is suggested here that when the veld in a compartment reaches a critical biomass, it should be burnt, to allow the veld to rejuvenate and to reduce the risk of uncontolled fires in the catchment areas. As a strong correlation between biomass and the spectral data of the MSS exists, it is suggested that monitoring plots of 100 or more pixels, be located in each compartment. These plots can be placed, so as to avoid shadowed areas, and can be located in the dominant veld type of the compartment. The mean pixel value for the monitoring plot can then, with the aid of a regression equation, be converted to a biomass value, representative of the biomass of the compartment. Based on this value, management decisions relating to burning can be made.

7.4.4. TOPOGRAPHICAL EFFECTS.

It was hoped that the information contained in the spectral values falling within the shadowed areas, would be sufficient to allow the task "itclus" to cluster the data into groups, which could be correlated with vegetation parameters. Based on the disappointing results obtained from the classifications of shadowed area imagery, it can be assumed that the amount of light in the four MSS bands, reflected from shadowed areas, is not sufficient to give a clear spectral signature of the vegetation. As it was found that only about seventeen percent of a mountainous area is in shadow on summer (February) imagery, and that most of this shadow area was located on steep cliff faces, it is suggested that for the compilation of thematic maps, for areas with severe topography,the following procedure should be considered.

1. The appropiate MSS bands or ratio combinations should be selected for the theme required and the shadow areas removed, by applying the mask described in section 6.7.2 of the report. Normal image processing procedures can then be applied to these images and the map for sun irradiated areas produced.

2. The detail of the shadow areas can be filled in by extrapolating the selected map parameters for shadowed areas. Aerial photography, field visits and other sources of information can be used to complement these extrapolations.

The level of accuracy of the map that would result from this procedure, is considered sufficient to satisfy general management needs, as they exist at present.

7.4.5. PROCEDURE FOR THEMATIC MAPPING.

Based on the experience gained in the production of the thematic map shown on page 136, the following detailed procedure is suggested for the production of thematic maps for mountainous areas, from multispectral imagery.

From the CCT, copy out sub-images onto disc files that cover the study site, in all the required bands. Geometrically correct these images for distortion and scale. Produce a mask capable of removing the shadowed areas, as described in section 6.7.2 of this report. The spectral value of 36, given as the cut off point,may vary from image to image and site to site, and may therefore need controlling. The ratio images selected for the map theme are created and the shadowed areas are removed from these, with the aid of the mask. From these images, training areas are selected and concatinated into a training image. This image is checked to ensure their representativeness of the whole study area. The training image is used to establish the signatures for the classification procedure. Ground reference data is collected along transsects in each training area and is used in the selection of the signatures. Statistics like the transformed divergence and the Jeffrey-Matusita distance, as well as bi-spectral plots are used in the final selection of the class signatures. These signatures are then used to classify the image of the whole study area and the shadowed areas are filled in by extrapolation, field control and from aerial photography. The map is evaluated and if it is found satisfactory, the final product can be prepared.

CHAPTER EIGHT

8. CONCLUSIONS.

This project was originally initiated for two main reasons. It was firstly to be a didactic exercise in remote sensing and digital image processing. In this, it is felt, it succeeded satisfactorily, as this report illustrates.

Secondly, it was to be the start of an investigation into the uses of LANDSAT imagery for the management of mountain catchment areas. The hypothesis set up for this project specifically, is that LANDSAT multispectral scanner digital imagery is a useful source of information, inspite of the presence of topographical shadow on the imagery, for the planning, monitoring and management functions of the mountain catchment areas of the fynbos biome.

Based on the results of the study, this hypothesis has been accepted and the following conclusions have been reached.

1.Shadow does significantly affect the imagery and cannot be satisfactorily compensated for by ratioing the various spectral bands or by classifying the shadowed areas separately. Ratioing does however, neutralize the effects of slope and aspect on the imagery, in areas receiving direct solar radiation.

2.Shadow areas are generally restricted and are largely confined to steep cliff areas. They can be effectively removed, together with water bodies, from the data base, by applying an image mask, created from band 7. In the final map product, these areas can be filled in by extrapolation, from field control, from aerial photography or from some other available reference source.

3.Ratioed LANDSAT multispectral imagery correlates well with biomass and other vegetation parameters suitable for monitoring vegetation maturity. A monitoring system using the information from the spectral data can readily be established in the mountainous areas.

4.The mapping of veld type proved disappointing. A sound fynbos classification system, based on leaf surface or some other parameter that correlates well with the spectral data, needs to be established, if multispectral data is to be successfully used for veld type mapping at this scale (1.25 000).

5.The transsect method of collecting ground reference data proved satisfactory and promises to be a useful method for obtaining regression equations for use in a monitoring system.

6.Multispectral data such as LANDSAT MSS data could form a useful basis for a mountain catchment digital information system, as MSS data correlates well with percentage cover, vegetation height, biomass, veld condition, aspect and other useful parameters. Combining MSS digital data with digitized topographic information, from which slope can be deduced, could for example, result in a useful fire index based on biomass, slope and aspect.

7.The pixel size of the MSS data (56 metres x 81 metres) and a mapping scale of 1:25 000 resulted in a map product, where the recognizability and detectability of many features, desirable at this scale, such as indigenous forest patches, old quarry sites, roads and rivers, were limited. At a scale of 1:50 000 or 1:100 000, where features of this type need to be of comparably larger size before being considered as mappable units, the MSS data would have resulted in a more acceptable map product.

8.The difficulty of identifying the accurate location of pixels in the field in mountainous terrain and the approximations of the geometric corrections performed by affine transformations, contribute to the difficulty of producing a suitable map from the MSS data at the scale of 1:25 000.

9.The Pips system, used for digital image processing during this project, did not meet all the requirements desired for this work. The arithmetical ability of the system is restricted, as it cannot perform operations such as log transformations, square roots or power functions, without the laborious task of incorporating programmes from the "Statistical Package for Social Sciences". Furthermore, it is not an interactive system and each stage of the processing must be done by means of a separate batch run. The only graphic output readily available from this system, as implemented at the University of Cape Town, is a line printer paper print-out. This system is implemented at the University of Cape Town, on the Sperry (Univac) main frame computer and contains none of its own hardware. As file space on a communal main frame is often severely limited, great care had to be taken in keeping file space requirements to a minimum.

The digital clustering algorithm (task "itclus") was not designed to cluster ratioed images, but in the absence of any alternative, it had to be used for this project.

10.For operational use of multispectral information in the management of mountainous conservation areas, an inhouse digital image processing system and the imagery supplied by the LANDSAT 4 thematic mapper (pixel size 30 metres x 30 metres), would provide satisfactory results. The LANDSAT 4 thematic mapper was specifically designed for vegetation mapping (Swain 1978).

CHAPTER NINE

9. RECOMMENDATIONS.

This project has been the first formal attempt at evaluating the uses of digital multispectral imagery in the management of fynbos mountain catchment areas. As such, it has served to only scratch the surface of this field of technology. It has also served as a useful didactic exercise.

Based on the experience gained during this project, the following recommendations are made.

1.In order to gain maximum benefit from this rapidly advancing technology, research into the usefulness of the image products created by the various sensors, should keep pace with their development. This rapid development is displayed by the decrease in pixel size over the past twenty years, from a pixel size of kilometres on the NOAA weather satellites of the 1960's, to the LANDSAT MSS pixel of 56 metres x 81 metres and the LANDSAT thematic mapper pixel of 30 metres x 30 metres, down to the SPOT satellites expected pixel size of 10 metres x 10 metres, due for launch in 1984.

2.The use of MSS data, which is readily available at present, should be used as an aid to the monitoring system being used by the Directorate of Forestry in the mountain catchment areas. The correlation of biomass with the spectral data of the MSS image, allows the maturity of the veld to be monitored, giving a clear indication of when the veld is mature enough for prescribed burning. The location of the spectral monitoring plots can be chosen in such a way as to avoid the influence that topographic shadow would have on the imagery.

3.Mapping with the MSS data at a scale of 1:25 000 did not prove to be as successful as was anticipated. Mapping at this scale will be far more successful, if the LANDSAT thematic mapper imagery, with the smaller pixel, is used. A scale of 1:50 000 or 1:100 000 is, I feel, the minimum recommended scale for mapping with the LANDSAT MSS digital data in mountainous areas.

4.The use of spectral data for veld type mapping should be further investigated. In this project, summer imagery was used and the vegetation classification system adapted for use took no cognizance of the spectral characteristics of the selected vegetation classes.

It is therefore recommended that attention be given to developing a classification system for fynbos, that is not only ecologically sound, but is also spectrally separable. This system should also be management orientated.

Furthermore, the spectral response of the fynbos should be studied to ascertain the most suitable season for image capture, so that the maximum spectral separability of the vegetation units is obtained. This study should include the possibility of using multitemporal imagery to obtain the maximum separability of vegetation classes.

5. This project was only able to investigate a limited

number of ratioed combinations of the MSS imagery. The field measurements obtained for correlating with the spectral information, was of a coarse nature. Future investigations should therefore look at ratioed images in more detail, especially at ratios, where the required arithmetic was not possible on the processing system used for this project. Field measurements should also be of a more exact nature.

6.The transsect method of field reference data collection used in this project proved satisfactory, however, the correlations were obtained by grouping both the spectral data and the field data into classes and using the means of these classes to obtain the equations. Comparing the individual field measurements with the individual spectral values of the pixels, is to be preferred.

7.The ultimate aim of all research in the field of digital processing, conducted by the Directorate of Forestry's Conservation Management Section, should be to establish a digital data base for all mountain conservation areas. This data base should not only contain spectral information and what can be deduced from it, but should also include other sources of data. Elevation information, hydrological information, cadastral information and all other useful management information that can be digitized, should be considered for this data base.

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APPENDIX ONE

GROUND REFERANCE DATA COLLECTION FORM

1 LOCATION

SCORE

83 DATE	TRAINING AREA NO.
TRANSECT NO.	DIRECTION.
POINT NO.	

1

2 REFLECTIVE INDEX

ASPECT.	SLOPE.

2

3 SHADOW

1 IN (>40)	2 OUT (<40)

3

4 BACKGROUND COLOUR

1 WHT	2 GRY	3 BRN	4 BLK

4

5 VELD CONDITION

Young mature senescent

0 1 2 3 4 5 6 7 8 9 10

5

6 VELD TYPE

1 LOW RESTIO	2 TALL RESTIO	3 RESTIO-SHRUB
4 RIVER SHRUB	5 FOREST	6 SHRUB (.75+)
7 MED SHRUB (.75-)	8 ALIENS	9 ___________

6

7 LEAF SURFACE

LARGE FLAT NARROW ROUND

0 1 2 3 4 5 6 7 8 9 10

7

8 VEGETATION COLOUR

1 DG	2 LG	3 GY	4 LB	5 BR

8

9 %COVER

DEAD	LIVE	B/GROUND

9

d

l

t

10 HEIGHT

10